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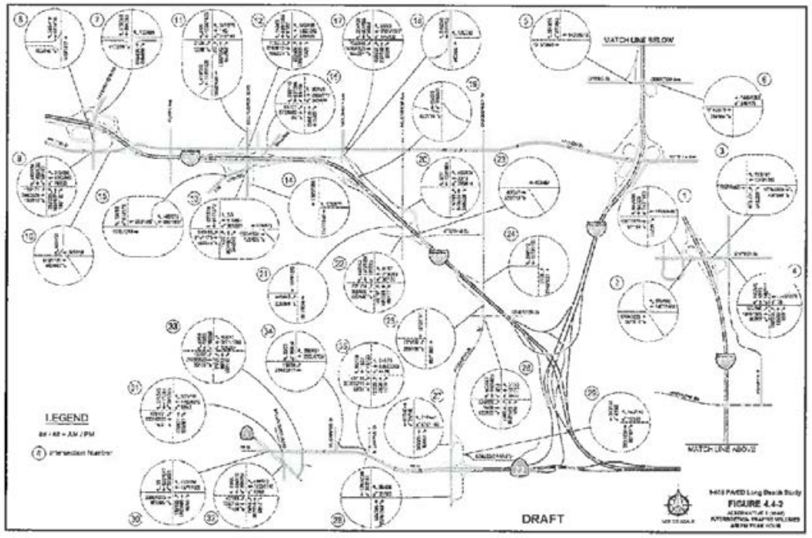

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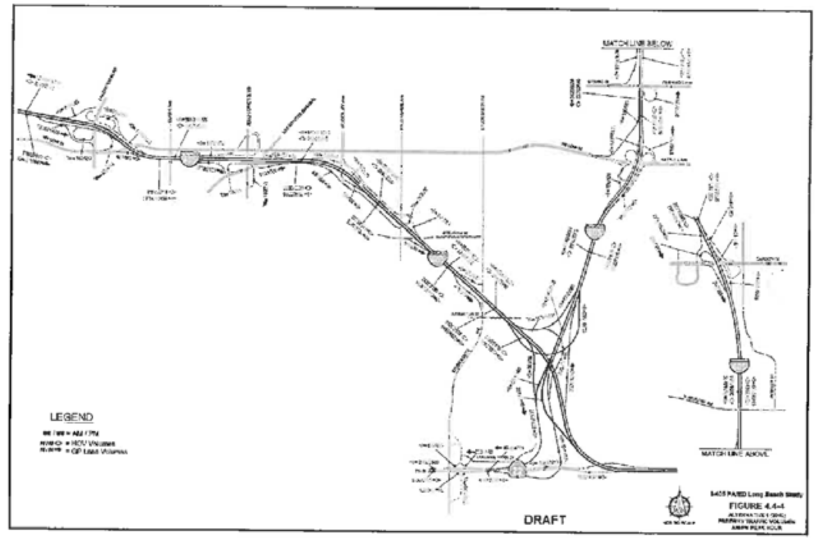

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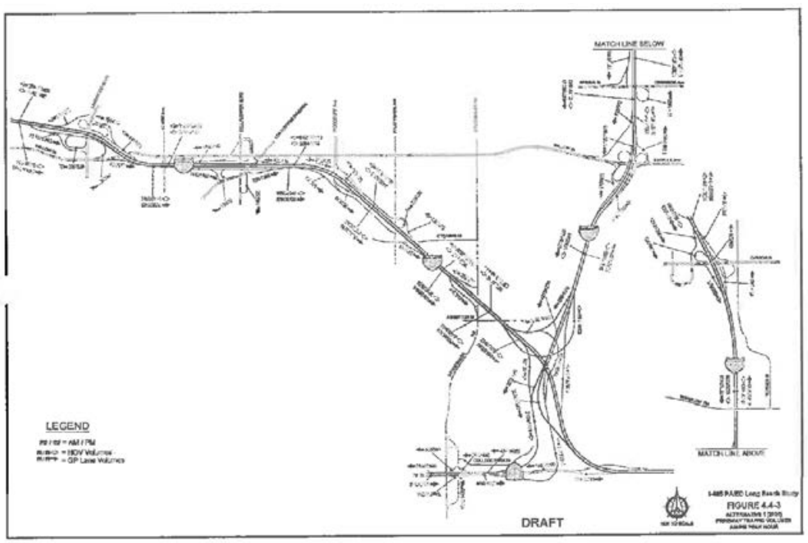

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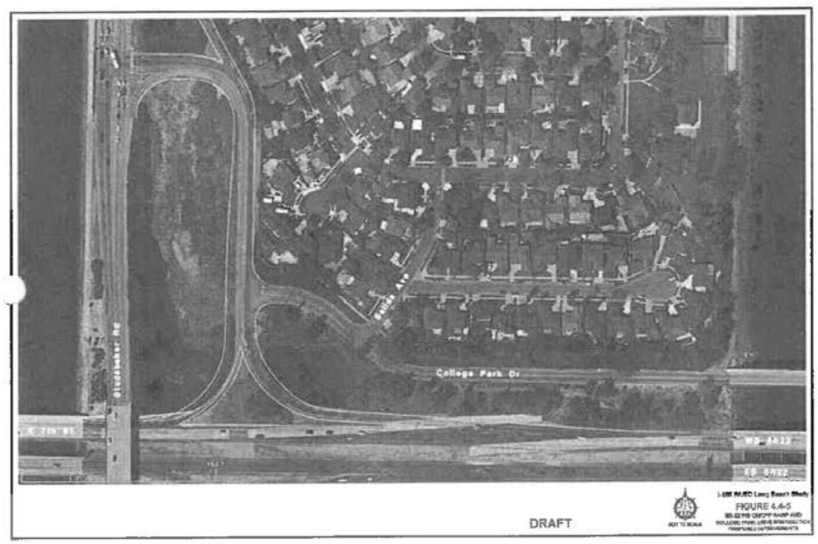

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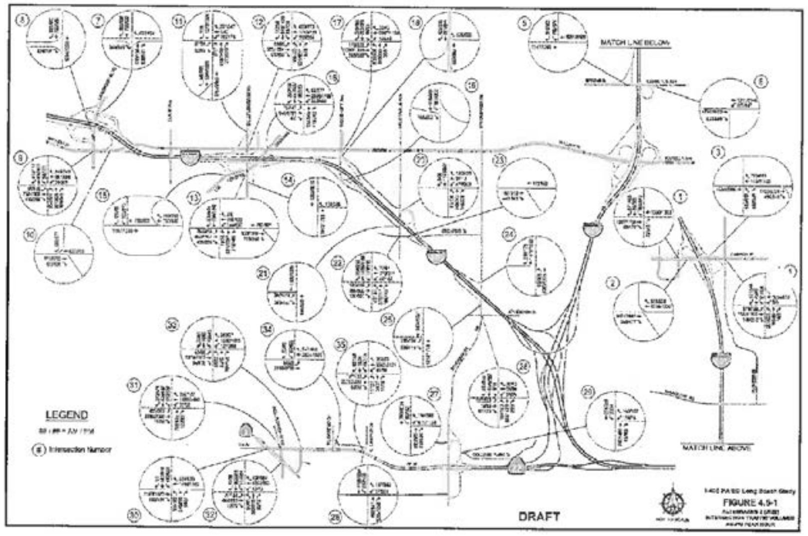

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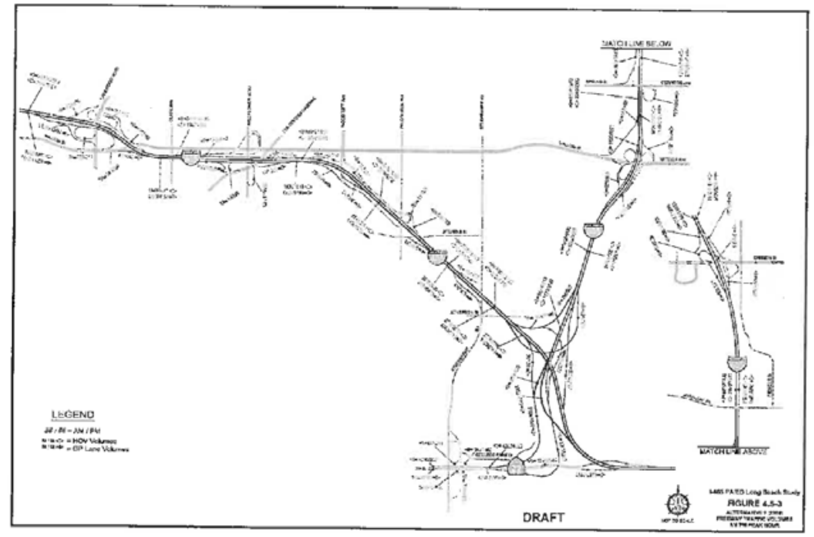

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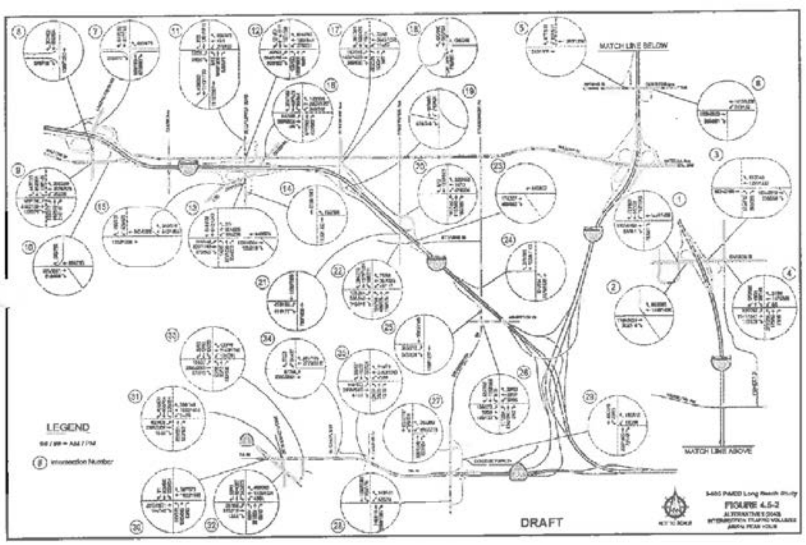

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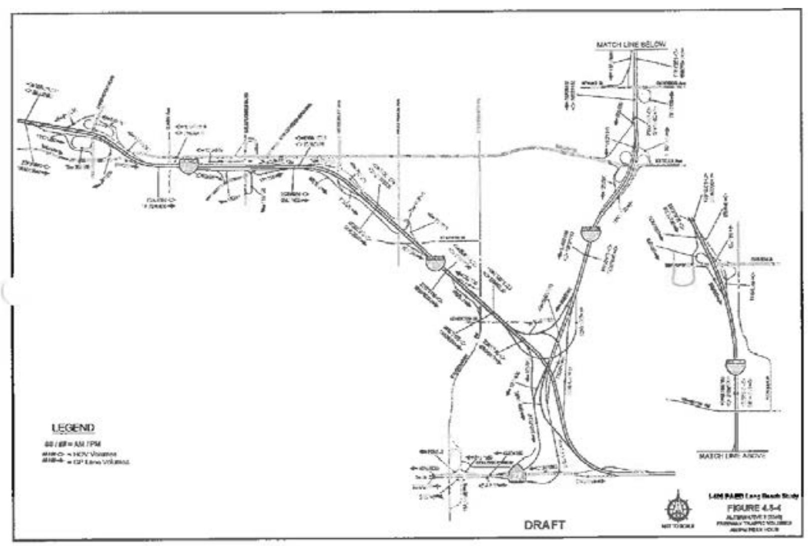

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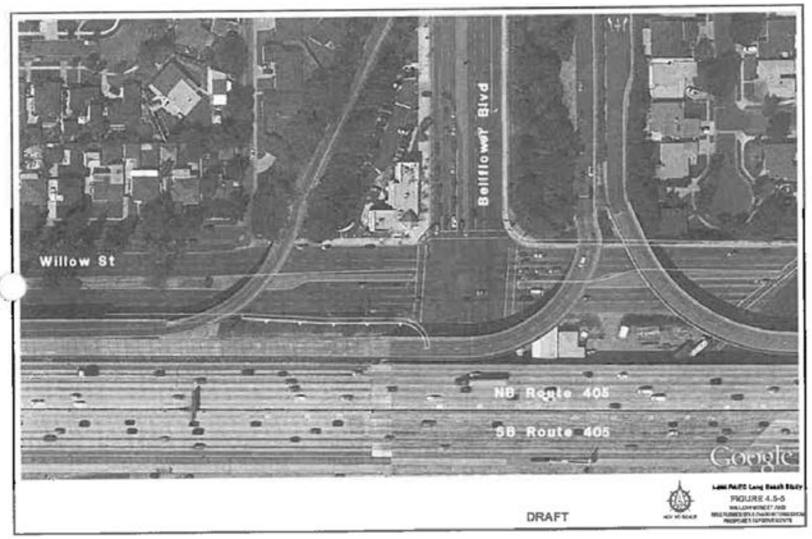

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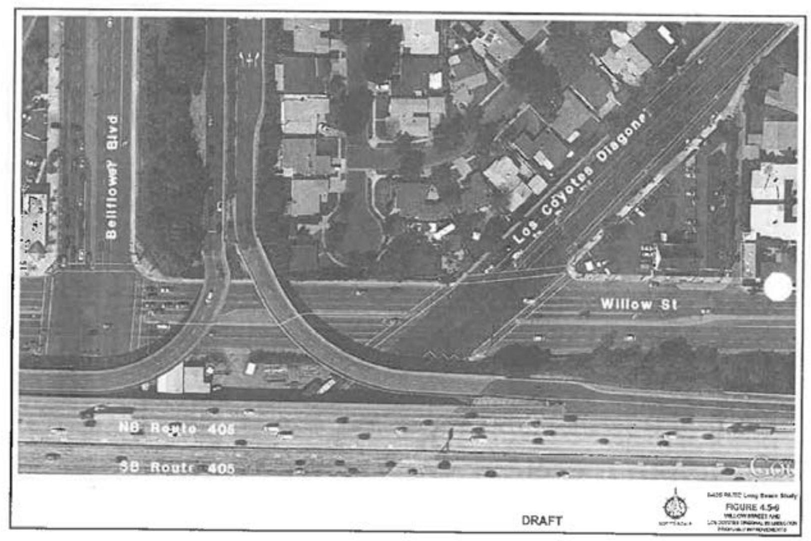

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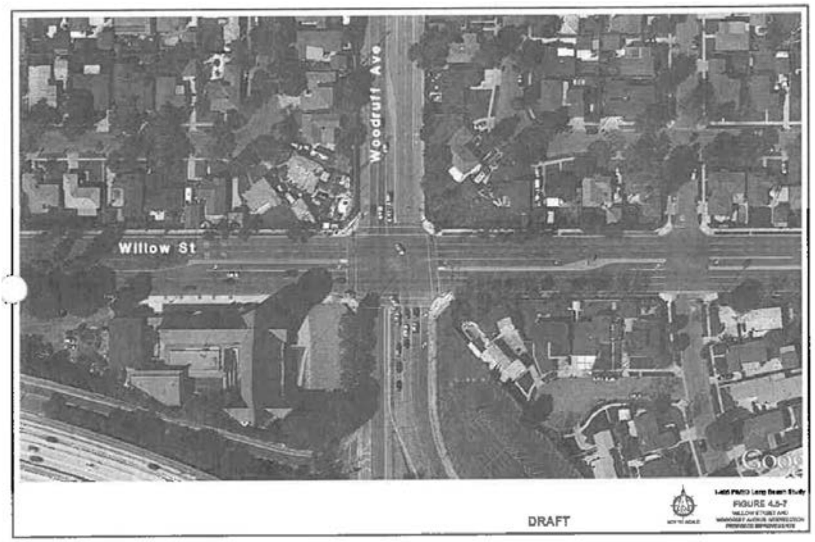

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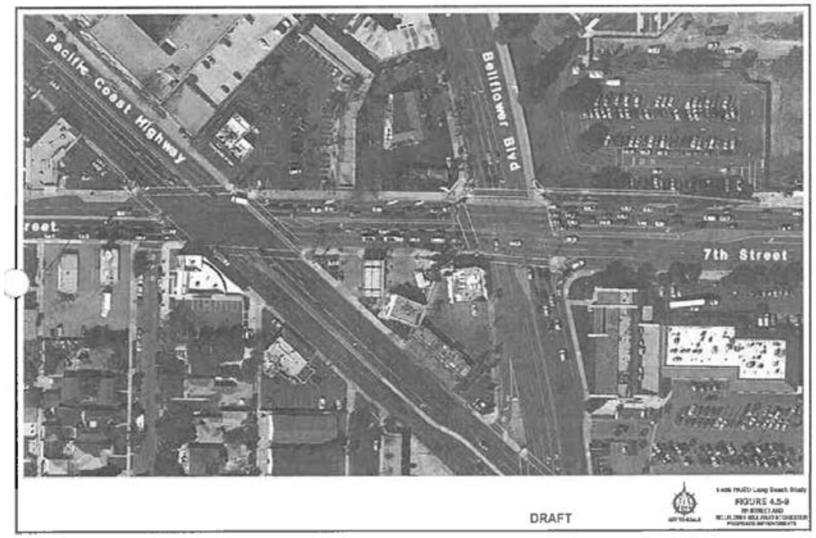

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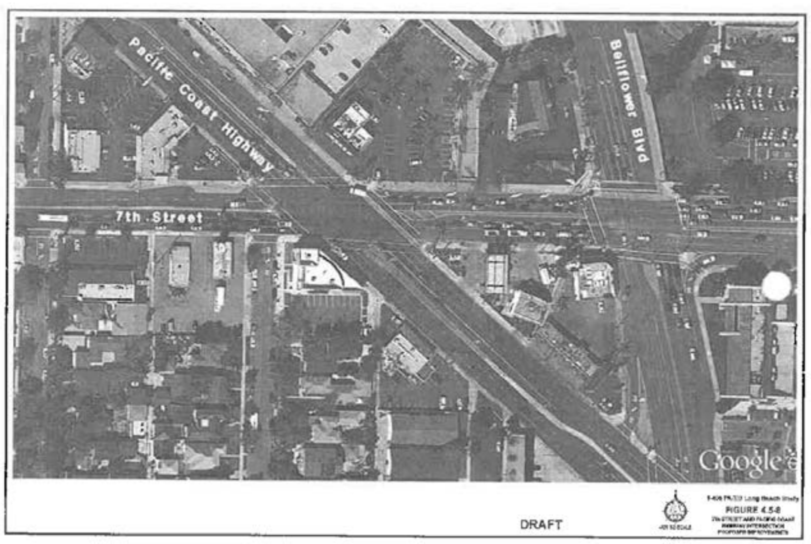

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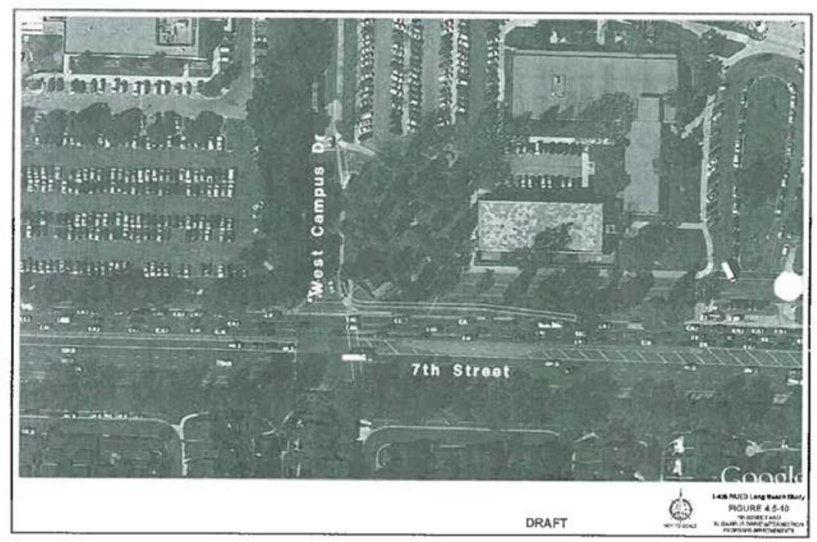

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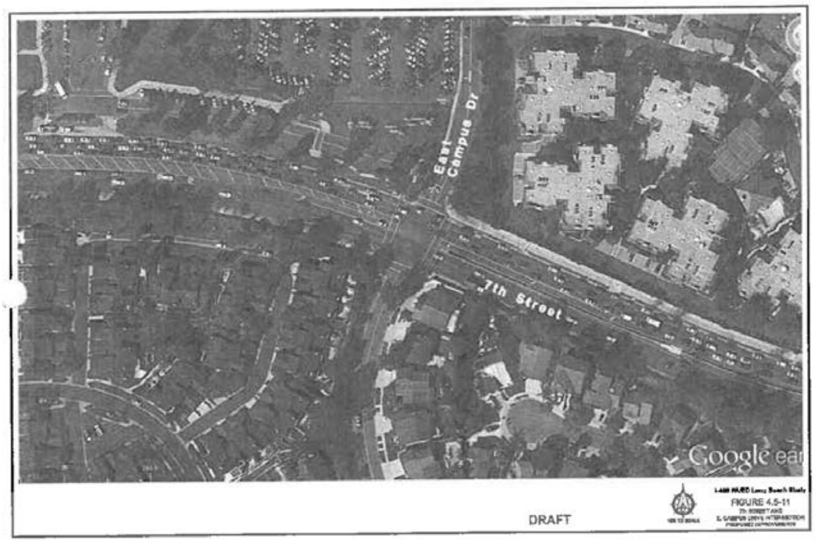

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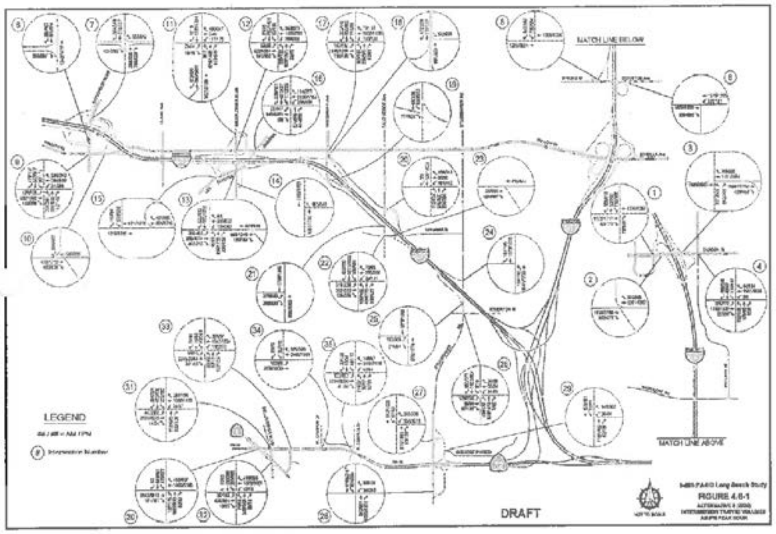

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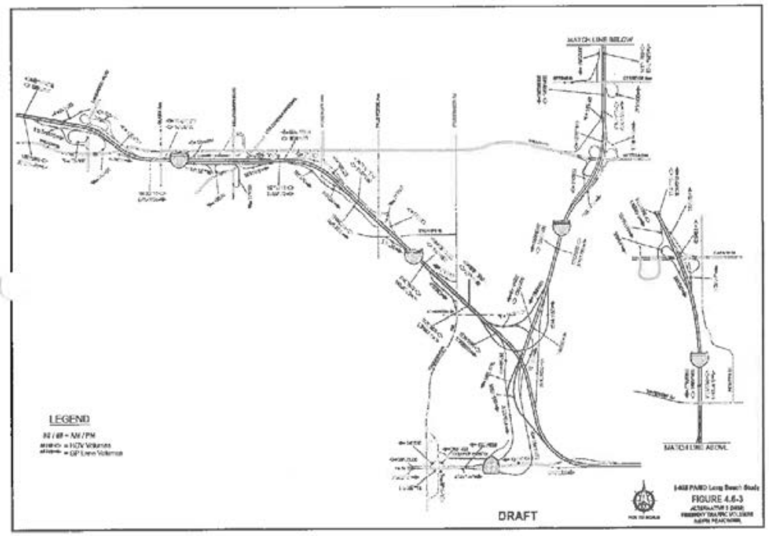

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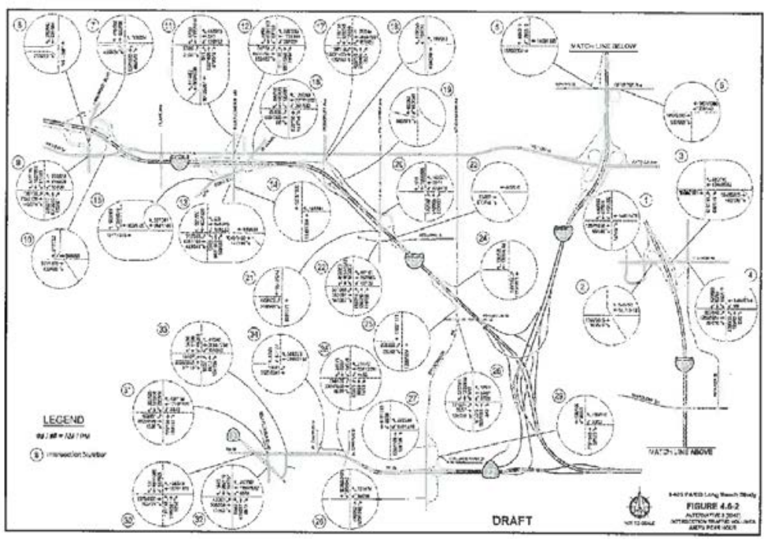

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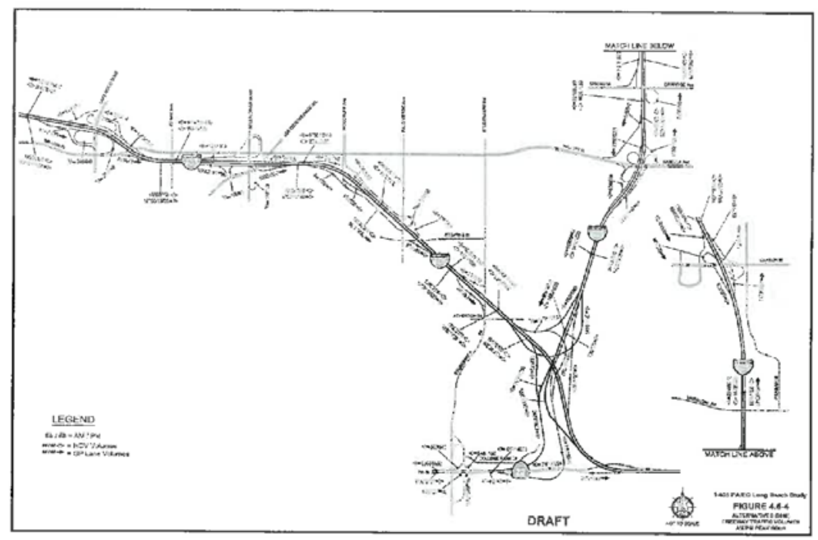

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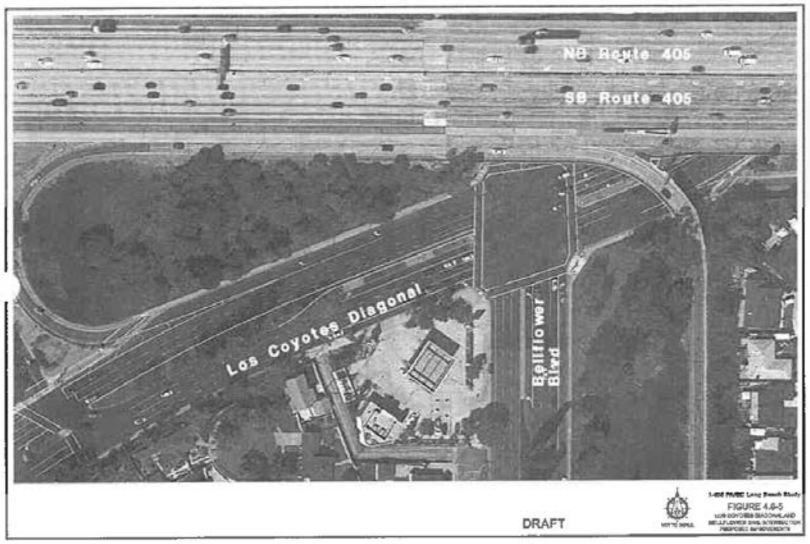

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Attachment 2

Correspondence from Jim Beil
OCTA Executive Director
June 25, 2013

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GL-9 (Continued)

OCTA

June 25, 2013

Mr. Sean Crumby
Director of Public Works
City of Seal Beach
211 Eight Street
Seal Beach, CA 90740

Dear Mr. Crumby:

As the environmental phase of the Interstate 405 (I-405) Improvement Project (Project) moves forward, staff continues to study issues previously raised by the I-405 corridor cities and other stakeholders. One of these issues relates to the existing soundwall along I-405 that parallels Almond Avenue in the City of Seal Beach (City) constructed in the 1970s.

Project plans for the three build alternatives have differing impacts to the soundwall: Project Alternatives 1 and 3 would not necessitate the reconstruction of the soundwall as both alternatives provide just one additional general purpose (GP) lane at this location. Alternative 2, however, does necessitate reconstruction of the existing soundwall as this alternative provides two additional GP lanes on I-405 along Almond Avenue, thus requiring some minimal additional right-of-way to accommodate the second GP lane.

Previously, the City proposed that the Project include non-standard features such as reduced widths for lanes and shoulders in order to reduce the Project footprint and eliminate the need to reconstruct the soundwall. Orange County Transportation Authority (OCTA) staff and consultants have met with the California Department of Transportation (Caltrans), City staff, and consultants to review these proposals.

Based on discussions with Caltrans, there is no justification to substantiate approval for any of the three proposed design exceptions to the mandatory design safety standards that would be required to leave the soundwall in place with Alternative 2.

Approval of the design exceptions must consider the tradeoffs between meeting the mandatory design safety standards on I-405 and the impacts to Almond Avenue. The I-405 in the vicinity of the Almond Avenue soundwall currently carries approximately 370,000 vehicles per day at speeds of up to 65 miles per hour or greater. Almond Avenue carries less than 5,000 vehicles per day at speeds of up to 30 miles per hour. Almond Avenue is 40-feet wide and has one lane in each direction and a parking lane on each side of the street. On-street parking on the north side of Almond Avenue is light to non-existent, and non-existent on the south side of Almond Avenue.

Orange County Transportation Authority
550 South Main Street / P.O. Box 14184 / Orange / California 92863-1584 / (714) 560-OCTA (6282)

GL-9 (Continued)

Mr. Sean Crumby
June 25, 2013
Page 2

State approvals of mandatory design safety standard exceptions are contingent upon implications to safety when not meeting standards. There are no safety implications related to the removal of parking on the south side of Almond Avenue. In comparison, this section of I-405 has the highest accident concentrations in Orange County. Maintaining design standards on I-405 significantly outweighs the minimal impacts to Almond Avenue when it comes to safety.

Attachment A provides a summary of the City proposals for Alternative 2 and reasoning why Caltrans has determined there is no justification to accept the proposed design exceptions to mandatory design safety standards.

Almond Avenue is approximately 5,500-feet long from Violet Street to Aster Street, including diversions around Almond Park. Alternative 2 will maintain one lane of traffic in each direction and parking on both sides of the street with the exception of approximately 100 feet where parking will only be feasible on one side of the street. This appears to be in general compliance with the City's Municipal Code. Attachment B is a copy of the City Municipal Code, Title 10, page 43, which provides the required travel lane and parking lane width for Almond Avenue, which is a residential collector street.

OCTA looks forward to working closely with City staff as the Project progresses to address all City concerns. OCTA holds regularly scheduled technical working group meetings, which include representatives from the City, and will work towards amenable solutions with the City and Caltrans.

OCTA and Caltrans staff are preparing the supplemental draft environmental impact report/environmental impact statement that is scheduled to be circulated for public review and comments in summer 2013. We look forward to the City's comments during the public review period.

Please feel free to contact me at (714) 560-5646 if you have any questions.

Sincerely,

Jim Beil, P.E.
Executive Director, Capital Programs

JB:nb
Attachments

c: Ms. Jill Ingram, Seal Beach City Manager

GL-9 (Continued)

I-405 Alternative 2
Proposed Design Exceptions to Mandatory Design Standards
To Avoid Relocation of the Almond Avenue Sound Wall

This document summarizes the three Highway Design Manual (HDM) Mandatory Design Standards and the proposed Design Exceptions to an Interstate 405 (I-405) Improvement Project Alternative 2 design to avoid impacting the existing sound wall between the I-405 and Almond Avenue in the City of Seal Beach, as well as safety implications of approval of these design exceptions.

Deviation from the three Mandatory Design Standards requires approval of Design Exceptions by State of California Department of Transportation (Caltrans) District 12 design staff in Irvine, Caltrans Headquarters design staff in Sacramento, and the Federal Highway Administration.

Proposed Design Exceptions to Mandatory Design Standards

Reference / Notes*	Highway Design Manual (HDM) Section & Feature	Location and Description (Length of Exception in Feet)	HDM Standard	Proposed
1	201.1 –Sight Distance	Northbound I-405 @ 4010' radius curve adjacent to west SR-22/North I-405 connector at right-of-way pinch point (615 feet)	750 feet	590 feet
2	301.1 –Traveled Way Width	Northbound I-405 west of SR-22 East (Total 5,565 ft) 11-foot-wide lanes for 2 HOV and 5 general purpose lanes (1,665 ft) 11-foot-wide lanes for 2 HOV and 2 general purpose lanes (3,200 ft) 11-foot-wide lanes for 1 HOV and 2 general purpose lanes (700 ft)	12 feet	11 feet
3	302.1 –Shoulder Width & 309.1(3)(a) - Minimum Horizontal Clearance	NB I-405 Left Median Shoulder (4,300 ft)	10 feet	8 feet

1

GL-9 (Continued)

*Notes

With respect to the three design exceptions identified in the table above, none of the proposals below are acceptable:

1. **Sight Distance** - Reducing sight distance below the standard has the potential to result in a driver's inability to see an object or stopped vehicle in time to stop or take evasive action before colliding with the object or stopped vehicle, resulting in a higher number of rear-end collisions.
2. **Traveled Way Width** - Proposed nonstandard narrow lanes may increase the potential for sideswipe accidents, since drivers have less room between themselves and vehicles in adjacent lanes.
3. **Shoulder Width / Minimal Horizontal Clearance** - Narrow shoulders decrease the protection of disabled and other stopped vehicles from traffic moving in the travel lanes and reduce the protection of motorists, police officers, service patrol workers, and others who must be outside their vehicles.

City of Seal Beach Municipal Code

The following page is taken from the City of Seal Beach Municipal Code, Title 10, Page 43, Table 10.40.010.A. (the Code) which outlines the Street Design Standards for a Residential Collector street such as Almond Avenue.

For Almond Avenue, the Code calls for a 36 foot minimum street width (curb-to-curb) to accommodate two travel lanes of 10 feet each and two parking lanes of 8 feet each. If the Mandatory Design Standards for lane and shoulder width on the I-405 are met, the sound wall would be relocated narrowing Almond Avenue from its current 40 foot width to approximately 36 feet west of Almond Park, allowing the two existing travel lanes and two existing parking lanes to be retained. East of Almond Park, for approximately 100 feet, Almond Avenue would be narrowed to between 40 and 34 feet. Two travel lanes and one parking lane would be provided along this 100 ft. stretch. As for the remaining 250 feet of impact, Almond Avenue would still provide two travel lanes and two parking lanes.

In summary, Almond Avenue is approximately 5,500 feet from Violet Street to Aster Street, including diversions around Almond Park. Per Table 10.40.010.A. the project will maintain one lane of traffic in each direction and parking on both sides of the street with the exception of approximately 100 feet where parking will only be feasible on one side of the street per the City of Seal Beach's Municipal Code.

2

GL-9 (Continued)

**Table 10.40.010.A
Street Design Standards**

Street Type	Total ROW (ft)	Curb-to-Curb ROW (ft)	Travel Lane Width	Number of Travel Lanes	Parking Lane Width (ft)	Pedestrian ROW (ft)	Supplemental Regulations
Local Residential Street	56-60	36-40	10	2	8	10	(i)
Residential Collector & Commercial Street	60	36-40	10	2	8	12	(ii)
Commercial Street	64	40	12	2	8	12	(ii)
Light Manufacturing Street	64	44	12	2	10	10	(iii)
Divided Street	108-130	84-106	11	4-6	8	12	(iv), (v)

(i) Narrower parking lanes and bulb outs can be considered on a case-by-case basis.
(ii) On streets fronting commercial districts solid sidewalks and tree grates are required.
(iii) Sidewalk may be eliminated and utilized as additional landscaping based on level of anticipated pedestrian activity, unless required pursuant to federal or State law.
(iv) Where on street parking is not permitted, replace parking lane with additional landscaping and Class 1 bike plan as appropriate.
(v) Center landscaped median to be provided, no greater than 16 feet wide.

B. Intersections. Intersection design shall not compromise public safety or emergency vehicle access. Final intersection design approval shall be by the Director of Public Works/City Engineer.

1. Additional Lanes. Streets should have turn lanes or more than 1 travel lane in each direction only if it can be demonstrated, through modeling or other reliable means, that more than temporary congestion is anticipated (Level of Service E or greater). Where a total of 4 or more travel lanes are planned, a minimum 15-foot wide planted median should be provided to reduce visual impacts of the pavement.

2. Curb-to-Curb Distances. Curb-to-curb distances at intersections should be minimized to reduce vehicular speeds and pedestrian crossing distances. At typical intersections, on-street parking should be replaced by corner bulb outs that minimize curb-to-curb distances and slow traffic. (See Figure 10.40.010.B.2: *Corner Bulb Outs*.)

Title 10 – page 43

City of Seal Beach | Municipal Code | Ord. No. 1557
Adopted 2008 - Revised 2011

GL-9 (Continued)

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GL-9 (Continued)

Attachment 3

Orange County Transportation Commission
High-Occupancy Vehicle Degradation Study Powerpoint
April 8, 2013

GL-9 (Continued)

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GL-9 (Continued)

OCTA

ORANGE COUNTY TRANSPORTATION AUTHORITY

High-Occupancy Vehicle Degradation Study

Powerpoint

GL-9 (Continued)

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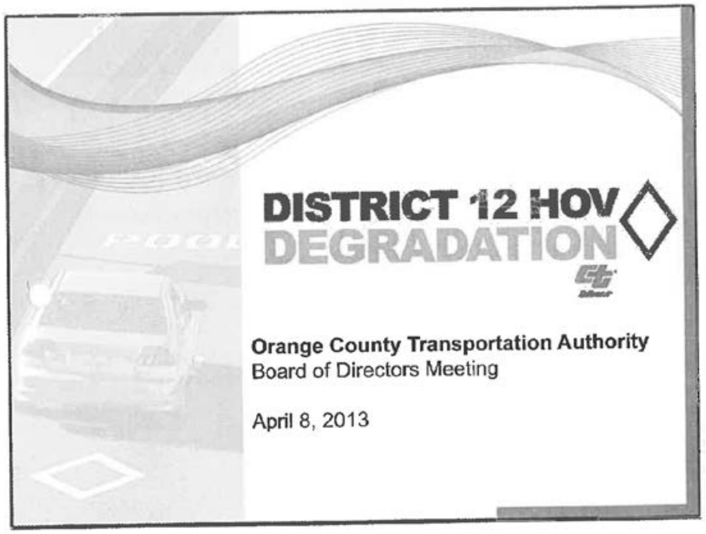

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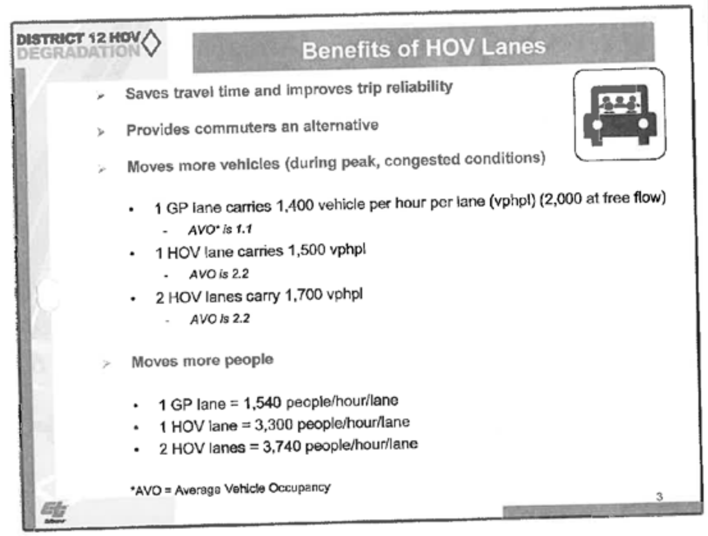

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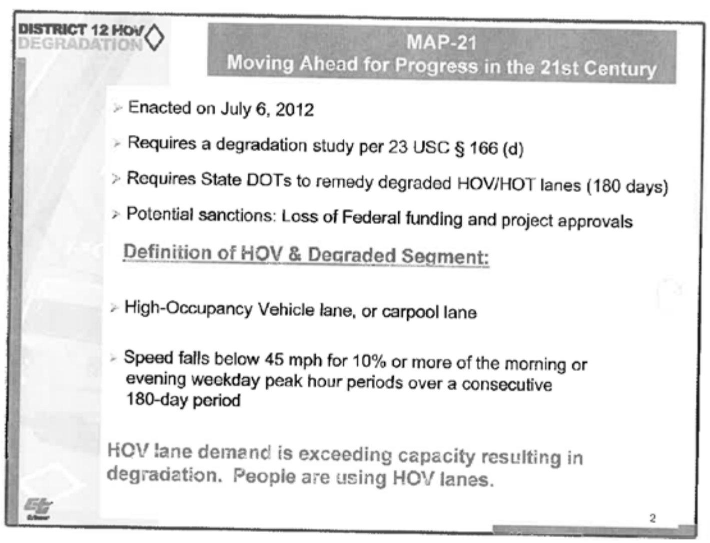

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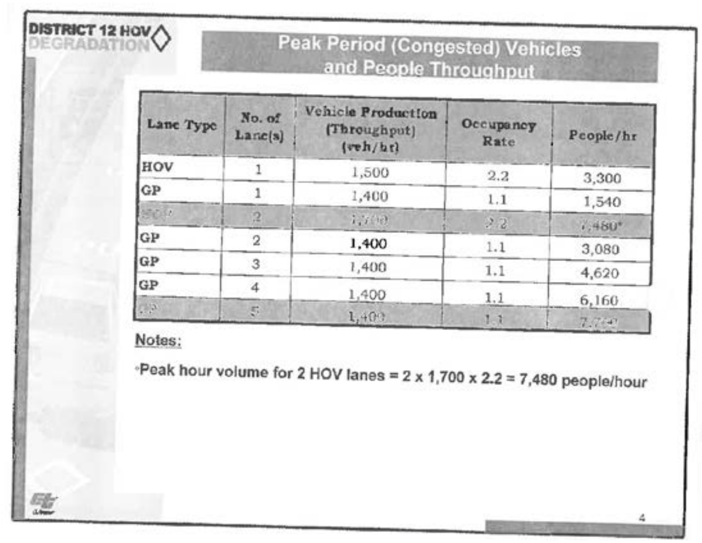
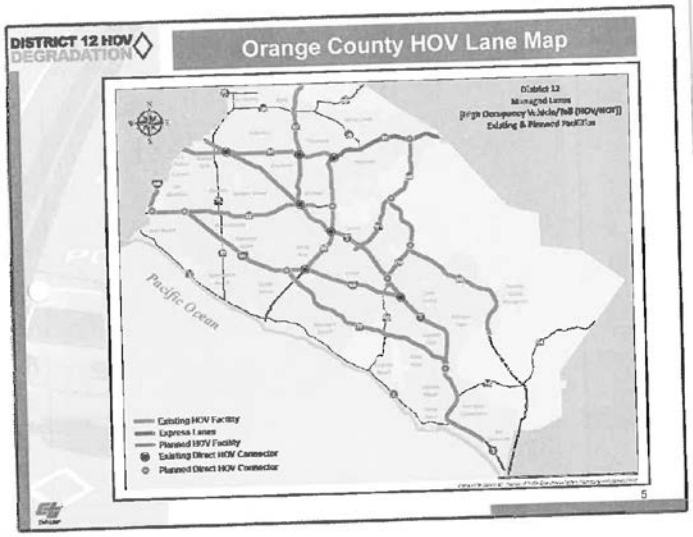


Lane Type	No. of Lane(s)	Vehicle Production (Throughput) (veh/hr)	Occupancy Rate	People/hr
HOV	1	1,500	2.2	3,300
GP	1	1,400	1.1	1,540
HOV	2	1,700	2.2	7,480*
GP	2	1,400	1.1	3,080
GP	3	1,400	1.1	4,620
GP	4	1,400	1.1	6,160
[illegible]	5	1,400	1.1	[illegible]

Notes:

*Peak hour volume for 2 HOV lanes = 2 x 1,700 x 2.2 = 7,480 people/hour

GL-9 (Continued)



GL-9 (Continued)

DISTRICT 12 HOV DEGRADATION

Least Effective Solutions to Address Degradation and Corridor Throughput

SOLUTION	PRO	CON
1. Increase enforcement	Address perceived lack of enforcement by public Serves as deterrent to violators	Limited congestion relief Require supplemental funding for periodic enforcement
2. Increase HOV violation fine	Reduce violation	Limited congestion relief
3. Prohibit Inherently Low Emission Vehicles (ILEV)	Minimal congestion relief in the HOV lanes	Increase congestion in GP lanes Counter to air quality strategies
4. Provide direct access to HOV lanes and connectors	Reduce weaving maneuver Remove pressure on nearby interchages	Additional capital costs
5. Peak period 3+	Relieve congestion in the HOV lanes	Empty lane syndrome Increase congestion in GP lanes Implementation challenges

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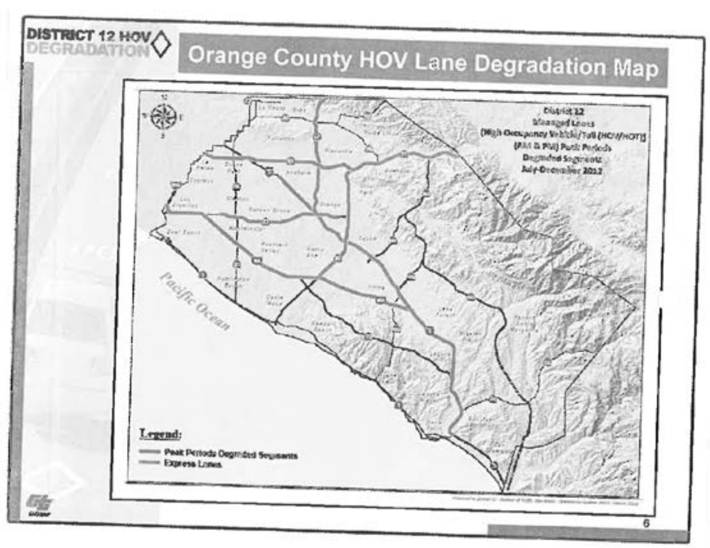
GL-9 (Continued)



GL-9 (Continued)

DISTRICT 12 HOV DEGRADATION

Most Effective Solutions to Address Degradation and Corridor Throughput

1. Raise occupancy (3+) (one lane)
2. Raise occupancy (3+) and convert to HOT (one lane)
3. Add second HOV lane (2+) (two lanes)
4. Add second HOV lane and convert to HOT (2+) (two lanes)
5. Add second HOV lane and convert to HOT, raise occupancy to (3+) (two lanes)

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GL-9 (Continued)

DISTRICT 12 HOV DEGRADATION

Most Effective Solutions to Address Degradation and Corridor Throughput

SOLUTION	PRO	CON
1. Raise occupancy (3+) (one lane)	Eliminate degradation	Empty lane syndrome Near-term congestion in GP lanes Perceived take-away
2. Raise occupancy (3+) and convert to HOT (one lane)	Same as (1) Improved travel time reliability Move more vehicles Manages congestion Potential revenue for corridor	Same as (1) May eliminate future ML options Tolling resistance Limited funding
3. Add second HOV lane (2+) (two lanes)	Same as (1) Improved travel time reliability Improved incident response Move more people and vehicles Allows 2+ to stay in lanes	Limited funding Potential right-of-way impact Near-term empty lane sydrome
4. Add second HOV lane and convert to HOT (2+) (two lanes)	Same as (2) and (3) Allows 2+ to stay in HOT lanes	Same as (3) Tolling resistance
5. Add second HOV lane and convert to HOT Raise Occupancy to (3+) (two lanes)	Same as (1) and (2) Improved incident response Move more people Greater options for single occupant vehicles	Same as (1), (3) and (4)

9

GL-9 (Continued)

DISTRICT 12 HOV DEGRADATION

Recommendations to Address Degradation & Corridor Throughput

Long-Term

- Add HOV lanes or HOT lanes (creating a two-lane system)

  As project opportunities arise

  Subject to funding availability

Short-Term

- Convert existing HOV lanes to HOT lanes and increase occupancy from 2+ to 3+

  Where long term options are not feasible

  Where GP capacity is added to corridor (ideal)

  Create a two-lane system when available

10

GL-9 (Continued)

DISTRICT 12 HOV DEGRADATION

THANK YOU

QUESTIONS OR CONCERNS?

James Pinheiro, PE
Deputy District Director, Caltrans District 12
Operations & Maintenance
Email: James_Pinheiro@dot.ca.gov

Additional information:

www.dot.ca.gov/Dist12
facebook.com/CaltransD12
twitter.com/@caltrans12

11

GL-9 (Continued)

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GL-9 (Continued)

OCTA

ORANGE COUNTY TRANSPORTATION AUTHORITY

High-Occupancy Vehicle Degradation Study

Handout

GL-9 (Continued)

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GL-9 (Continued)

California Department of Transportation, District 12
High Occupancy Vehicle Degradation Study
Responses to Committee Comments

At the April 1, 2013 Regional Planning and Highways Committee (Committee) meeting the State of California Department of Transportation (Caltrans) made a presentation on the status of High Occupancy Vehicle Lane (HOV) operations on Orange County freeways. They also outlined possible near–term and long-term solutions to address degraded HOV facilities. The impetus for the effort is related to changes in transportation funding legislation. This presentation also is being provided to the full Board of Directors (Board) on April 8, 2013. A list of Committee questions and preliminary responses are provided below.

Director Donchak

Question: Is there anything that would prohibit HOV violation fines from matching the cost of added enforcement in order to be revenue neutral?

Response: HOV enforcement is typically performed on an overtime basis by the California Highway Patrol and as such there are limited resources. In addition, this approach would only provide a partial solution as it could address no more than five percent of the degradation issues.

Director Miller

Question: Do we have degradation data by freeway segment?

Response: Yes. Caltrans is expected to provide this information within the next several weeks.

Question: By what percentage will the proposed solutions fix degradation?

Response: It is unknown precisely what percentage reduction each proposed solution would provide. However, solutions have been generally characterized as "least effective" and "most effective."

Question: What is the Traffic and Revenue projection for one High Occupancy Toll (HOT) lane?

Response: This analysis has not been completed and would require an amendment to the Parsons Transportation Group agreement. It would take approximately four months to complete.

GL-9 (Continued)

Director Murray

Question: When does the clock start ticking for the 180 days?

Response: Once Caltrans Director, Malcolm Dougherty, signs the HOV Degradation Study report and transmits it to the Federal Highway Administration (FHWA), Caltrans has 180 days to identify a plan and begin implementing solutions to address degradation.

Vice Chairman Nelson

Question: How will the degradation solutions be paid for?

Response: Degradation solutions are subject to funding availability and would be implemented as project opportunities arise.

Director Spitzer

Question: What is the State of California's position on where excess revenues should be spent?

Response: SBx4 indicates excess toll revenues may be paid to the regional transportation agency for use in improving public transportation in and near the project boundaries.

Question: How is Caltrans Headquarters handling the degradation findings statewide?

Response: Caltrans Headquarters is encouraging each district to explore remedies and districts are looking at similar solutions to those presented to the Committee. FHWA would like to see degradation remedies within 180 days, but if not feasible a plan must be submitted within the 180 day timeframe.

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GL-9 (Continued)

Attachment 4

City of Long Beach
I-405 Freeway Improvement Project Letter and Memorandum
July 17-18, 2012

GL-9 (Continued)

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GL-9 (Continued)

City of Long Beach
Working Together to Serve

Memorandum

Date: July 18, 2012

To: Patrick H. West, City Manager

From: Michael P. Conway, Director of Public Works

For: Mayor and City Council

Subject: I-405 Improvement Project

Orange County Transportation Authority (OCTA) and Caltrans are implementing a highway improvement project known as the I-405 Improvement Project. The proposed project will widen the San Diego Freeway (I-405) between the Corona del Mar Freeway (SR-73) and the San Gabriel River Freeway (I-605).

Several build options are under consideration. Options range from addition of one lane at various locations, to addition of two lanes in each direction. The project is currently in the environmental phase. The draft EIR / EIS was released for public review May 18, 2012. The public comment period ended July 17, 2012.

On July 3, 2012, the Long Beach City Council adopted a motion to address potential impacts to the City of Long Beach from this Caltrans project. Staff has reviewed the draft EIR / EIS and has determined the document does not address traffic impacts in City limits, as requested by the City in a letter dated October 22, 2009 in response to the Notice of Preparation. Furthermore, the document fails to demonstrate any inter - county coordination between OCTA and the Metropolitan Transportation Agency, and Caltrans Districts 12 and 7.

The City submitted the attached letter dated July 17, 2012 to Caltrans to describe the City's concerns with the draft EIR / EIS. Staff will continue to work with OCTA and Caltrans staff to assure potential traffic impacts in City limits are identified and mitigated.

Additional information regarding the project may be found at:

http://www.octa.net/I-405/IPO.aspx

If you have any questions about the information contained in this memorandum, please contact Derek Wieske, Assistant City Engineer, at extension 6386.

P/cm/fy12/mayor and city council/I-405 Improvement 7-18-12.doc

GL-9 (Continued)

CITY OF LONG BEACH

DEPARTMENT OF PUBLIC WORKS

333 WEST OCEAN BOULEVARD • LONG BEACH, CA 90802 • (562) 570-6383 • FAX (562) 570-6012

July 17, 2012

Smita Deshpande
Caltrans District 12, Branch Chief
Attn: 405 DEIR - DEIS Comment Period
2201 Dupont Drive, Suite 200
Irvine, CA 92612

Re: Draft Environmental Impact Report / Environmental Impact Statement for the San Diego Freeway (I-405) Improvement Project

Dear Ms. Deshpande:

Thank you for the opportunity to review the Draft Environmental Impact Report / Environmental Impact Statement for the San Diego Freeway (I-405) Improvement Project (Project). On July 3, 2012, the Long Beach City Council adopted a motion to address potential traffic impacts to the City of Long Beach from this Caltrans Project. After careful review of the draft EIR/S, as well as a recent meeting with Caltrans and OCTA staff to discuss the City's concerns, the City of Long Beach respectfully submits the attached comments.

As a Participating Agency of the Project, Long Beach submitted comments in 2009, in response to the original Notice of Preparation. The City is disappointed that many of the issues raised at that time are not addressed in the current draft EIR/S. The 2009 comment letter, dated October 22, is attached for reference, and notes the City's request that regional traffic impact evaluations, including traffic movements at arterial ramps in the City of Long Beach, be included in the draft EIR/S. Since the release of the draft EIR/S, Long Beach sees the document is noticeably silent on traffic impacts immediately north of the project area, and in the City of Long Beach. Given the importance that traffic impact studies immediately north of the project area be included in the EIR/S, Long Beach is reiterating the City's request for Caltrans to conduct and publish traffic impact evaluations consistent with those described in the attached comments.

Additionally, the Project proposes signage and striping changes in the County of Los Angeles, but the draft EIR/S fails to provide evaluation of traffic flow and potential impacts within the City of Long Beach. By not studying traffic flow north of the county-line, this draft EIR/S is inadequate.

The draft EIR/S also does not demonstrate that the proposed Project has been planned in coordination with the Metropolitan Transportation Authority and Caltrans District 7. The draft EIR/S fails to acknowledge previous intercounty planning efforts, including the Orange and Los Angeles Intercounty Transportation Study, which was completed jointly by the

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GL-9 (Continued)

Smita Deshpande
July 17, 2012
Page 2

Orange County Transportation Authority and the Metropolitan Transportation Agency in 2005. The study proposes several conceptual alternatives, including the addition of one general-purpose lane in each direction to the I-405 freeway from the I-605 freeway to the I-710 freeway.

On behalf of the City, Iteris, Inc. was contracted to conduct a review of the City's 2009 comment letter on the NOP and of the DEIR / EIS document. Iteris' written summary of its technical review, dated July 17, 2012, is attached for reference.

The City of Long Beach recognizes the need for improvements to mitigate congestion along the I-405 freeway, and looks forward to working with Caltrans and OCTA to ensure that potential traffic impacts within Long Beach boundaries are identified and mitigated, and that intercounty planning and coordination can be effectively performed. In the spirit of improving transportation through Southern California, Long Beach respectfully submits the attached comments.

Sincerely,

Mike Conway, Director of Public Works
City of Long Beach

cc: Mayor and Members of the City Council

GL-9 (Continued)

CITY OF LONG BEACH

DEPARTMENT OF PUBLIC WORKS

333 WEST OCEAN BOULEVARD • LONG BEACH, CA 90802 • (562) 570-6383 • FAX (562) 570-6012

October 22, 2009

Smita Deshpande
Branch Chief
Caltrans District 12
Attn: 405 Scoping
2201 Dupont Drive, Suite 200
Irvine, CA 92612

Subject: Notice of Preparation of a Draft EIR for the Caltrans San Diego Freeway (I-405) Improvement Project

Dear Ms. Deshpande:

Thank you for the opportunity to review the Notice of Preparation for the San Diego Freeway (I-405) Improvement Project. The following comments are submitted for your consideration in the preparation of the Draft EIR.

1. The City of Long Beach respectfully requests the Draft EIR evaluate both operational and construction - related impacts to traffic on the freeway system and adjacent arterial streets.

2. It's the City of Long Beach's understanding Caltrans currently does not plan to add lanes to the I-405 freeway north of the I-605 freeway. It's unclear how the proposed additional lanes would integrate thru the interchange with the existing freeway segments that won't be widened. The proposed project could create potential significant traffic flow impacts due to capacity constraints and the creation of a bottleneck thru the interchange.

3. The City of Long Beach respectfully requests that Caltrans consider the combined impacts of the West County Connectors project and the proposed new project, which would result in the addition of up to three lanes in each direction beyond what exists today.

4. The City of Long Beach respectfully requests that Caltrans use regional modeling software to determine the potential diversion of traffic on freeway segments within Los Angeles County resulting from any bottlenecks created by the project alternatives.

5. The City of Long Beach respectfully requests the study area be expanded to include the I-405 corridor from Lakewood Boulevard to the I-605 freeway and the study include evaluation of impacts to traffic movement in the expanded study area, including movements at the Lakewood Boulevard, Bellflower Boulevard, Woodruff Avenue and Palo Verde Avenue ramps.

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GL-9 (Continued)

6. The City of Long Beach respectfully requests the study area be expanded to include CA-22 from the I-405 freeway to CA-1. It's possible that CA-22 into Long Beach could become a diversion around the bottleneck created thru the interchange.

7. The City of Long Beach respectfully requests the study area be expanded on the I-605 freeway from the I-405 to Carson Street. It's possible that traffic currently using the I-405 could divert to the I-605 to avoid the bottleneck created thru the interchange.

8. The proposed project may create a potential significant impact in the form of substantial traffic disruption on streets within Long Beach during construction. Traffic mitigation may be required in Long Beach to accommodate additional traffic on arterial streets and to keep commuter traffic out of neighborhoods during the construction phase. The City of Long Beach respectfully requests that a preliminary Traffic Management Plan be developed as a part of the EIR process.

Thank you again for the opportunity to review the Notice of Preparation for the San Diego Freeway (I-405) Improvement Project. The City of Long Beach looks forward to working with Caltrans and OCTA staff to resolve the outstanding issues identified in this comment letter.

Sincerely,

David Roseman
City Traffic Engineer

cc: Mark Christoffels
Michael Conway

GL-9 (Continued)

ITERIS

I-405 Improvement Project DEIR/EIS Comments, July 17, 2012

July 17, 2012

David Roseman
City Traffic Engineer
City of Long Beach
333 W. Ocean Boulevard
Long Beach, CA 90802

Re: Review of OCTA San Diego Freeway (I-405) Improvement Project DEIR/EIS and Supporting Documentation

Dear Mr. Roseman,

Iteris, Inc. has completed the review of the Orange County Transportation Authority (OCTA) San Diego (I-405) Freeway Improvement Project Draft Environmental Impact Report/Environmental Impact Statement. Our comments are focused in two sections; 1) how the DEIR/EIS documentation responds or fails to adequately respond to the City of Long Beach's 2009 Notice of Preparation (NOP) comment letter, and 2) other general review of the DEIR/EIS and supporting materials with respect to issues of interest to the City of Long Beach. In this letter we first summarize our review of the comment letter and associated issues, and then we summarize our overall comments on other DEIR/EIS-related issues and analyses.

I-405 Improvement Project DEIR/EIS – 2009 CITY OF LONG BEACH NOTICE OF PREPARATION COMMENTS

In October of 2009, a comment letter was submitted to Caltrans District 12 by the City of Long Beach in response to the NOP of the Draft EIR for the Caltrans San Diego Freeway (I-405) Improvement Project (herein known as "proposed project"). In that letter, the City of Long Beach expressed several concerns with respect to the limits of the proposed project and its potential impact on the City of Long Beach.

With respect to the City of Long Beach's 2009 NOP comments, Iteris, Inc., on behalf of the City, has reviewed the May 2012 I-405 Improvement Project DEIR/EIS, and has evaluated whether or not the comment was taken into consideration partially or in its entirety. The City's NOP comments from 2009 are listed below, along with a description of how the comment was addressed in the I-405 Improvement Project DEIR/EIS.

1. **The City of Long Beach respectfully request the Draft EIR evaluate both operational and construction-related impacts to traffic on the freeway system and adjacent arterial streets.**

   <u>This comment was only partially addressed in the DEIR/EIS. Additional information regarding how the 2009 City of Long Beach NOP Comment 1 was not adequately addressed is provided below.</u>

   Construction-related impacts associated with the proposed project were not evaluated in detail on the freeway system or on adjacent arterial streets in the proposed project study area or in the City of Long Beach. Rather, a Transportation Management Plan (TMP) was prepared to present the overall framework for traffic management during construction. The TMP includes general topics such as construction staging, closures and lane restrictions, demand management, alternate route strategies, and contingency plans, to name a few. Although the Draft TMP provides a list of ramp/street closures and lane restrictions, it does not evaluate construction-related level of service impacts in the proposed project study area or in the City of Long Beach.

GL-9 (Continued)

ITERIS

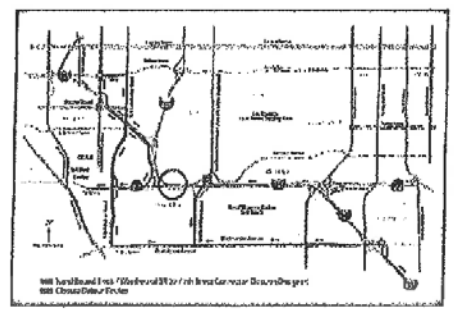
I-405 Improvement Project DEIR/EIS Comments, July 17, 2012

As discussed under Chapter 3.1, Section 3.1.6 Traffic and Transportation/Pedestrian and Bicycle Facilities, Comment 9, the I-405 southbound off-ramp at Seal Beach Boulevard is expected to be closed between 10 to 30 days during construction. Closure of the Seal Beach Boulevard off-ramp will likely result in cut-through traffic in the City of Long Beach. The DEIR/EIS for the proposed project states that tentative detours for the ramp closures are identified in the Ramp Closure Study (RCS), but when the RCS was reviewed, detours associated with the Seal Beach Boulevard southbound ramp were not provided. Detour routing analysis is critical to ensure efficient mobility through the City of Long Beach and should have been performed, as previously requested.

It should be noted that before construction of the northbound I-405/Westbound SR-22/7th Street Connector closure associated with the West County Connectors project, OCTA presented information at a neighborhood association meeting related to traffic detours through parts of east Long Beach. During construction of the I-405/7th Street connector bridge, four detours were provided, as shown in **Figure 1** below. In addition, OCTA helped mitigate traffic associated with the detour route via signal synchronization and various improvements to the Stearns Street freeway on-ramp, the 2nd Street and North Studebaker Road intersection, and the southbound I-405 and westbound SR-22 ramps. The DEIR/EIS should, at a minimum, provide preliminary detour routes and projected traffic impacts associated with the I-405 Seal Beach Boulevard southbound off-ramp closure during construction.

Operational impacts on the freeway system and on a limited number of arterial streets were addressed in the DEIR/EIR. However, only a limited number of interchanges and arterial street intersections along I-405 between SR-73 and I-605 were evaluated. No interchanges or arterial intersections were evaluated on I-405 north of I-605 in the City of Long Beach.

Figure 1: West County Connectors Project, Detours and Alternative Routes for I-405/7th Street Connector



2. **It's the City of Long Beach's understanding Caltrans currently does not plan to add lanes to the I-405 freeway north of the I-605 freeway. It's unclear how the proposed additional lanes would integrate thru the interchange with the existing freeway segments that won't be widened. The proposed project could create potential significant traffic flow impacts due to capacity constraints and the creation of a bottleneck thru the interchange.**

   <u>This comment was not taken into consideration in its entirety in the DEIR/EIS. Additional information regarding how the 2009 City of Long Beach NOP Comment 2 was not adequately addressed is provided below.</u>

GL-9 (Continued)

ITERIS

I-405 Improvement Project DEIR/EIS Comments, July 17, 2012

The proposed project extends along I-405 between SR-73 and I-605. The DEIR/EIS did not evaluate the impacts associated with the drop of one to two general purpose lanes (Alternatives 1 or 2), or the drop of two Express Lanes (Alternative 3) on I-405 north of I-605 in the City of Long Beach. It remains unclear how the added lanes will transition beyond the Orange County line into Los Angeles County and the City of Long Beach and the operational impacts associated with the lane transitions. An additional detailed review relating to this comment is provided under the discussion of Chapter 2, Project Alternatives, Comment 1 and Chapter 3.1, Section 3.1.6 Traffic and Transportation/Pedestrian and Bicycle Facilities, Comment 4.

3. **The City of Long Beach respectfully requests that Caltrans consider the combined impacts of the West County Connectors project and the proposed new project, which would result in the addition of up to three lanes in each direction beyond what exists today.**

<u>This comment was addressed in the DEIR/EIS.</u>

The West County Connectors project was incorporated into the proposed project. The Traffic Study explains that the No Build Alternative represents "baseline" conditions. With this alternative no additional lanes or interchange improvements would be constructed. Two projects were assumed to be complete under all future conditions; the SR-22 Freeway West County Connectors project from SR-22 east to I-605 (will add a second HOV lane in each direction and HOV direct connectors between I-605 and I-405 to/from the south and also between SR-22 east and I-405 to/from the north), and continuous access HOV lanes along I-405 throughout the study area (p.1-8).

4. **The City of Long Beach respectfully requests that Caltrans use regional modeling software to determine the potential diversion of traffic on freeway segments within Los Angeles County resulting from any bottlenecks created by the project alternatives.**

<u>This comment was not taken into consideration in its entirety in the DEIR/EIS. Additional information regarding how the 2009 City of Long Beach NOP Comment 4 was not adequately addressed is provided below.</u>

Traffic forecasts for the proposed project were developed using the OCTA Model (OCTAM). However, OCTAM was not used to evaluate the potential diversion of traffic associated with the proposed project in Los Angeles County or in the City of Long Beach. The modeling methodology is also flawed in that it does not include model runs for each alternative. An additional detailed review relating to this comment is provided under the discussion of Chapter 3.1, Section 3.1.6 Traffic and Transportation/Pedestrian and Bicycle Facilities, Comment 4.

5. **The City of Long Beach respectfully requests that the study area be expanded to include the I-405 corridor from Lakewood Boulevard to the I-605 freeway and the study include evaluation of impacts to traffic movement in the expanded study area, including movements at the Lakewood Boulevard, Bellflower Boulevard, Woodruff Avenue and Palo Verde Avenue ramps.**

<u>This comment was not taken into consideration in the DEIR/EIS. Additional information regarding how the 2009 City of Long Beach NOP Comment 5 was not adequately addressed is provided below.</u>

The study area was not extended west to include the I-405 corridor from Lakewood Boulevard to the I-605 freeway, and movements at Lakewood Boulevard, Bellflower Boulevard, Woodruff Avenue and Palo Verde Avenue ramps were not considered, per the City of Long Beach's request.

GL-9 (Continued)

ITERIS

I-405 Improvement Project DEIR/EIS Comments, July 17, 2012

6. **The City of Long Beach respectfully requests that the study area be expanded to include CA-22 from the I-405 freeway to CA-1. It's possible that CA-22 into Long Beach could become a diversion around the bottleneck created thru the interchange.**

<u>This comment was not taken into consideration in its entirety in the DEIR/EIS. Additional information regarding how the 2009 City of Long Beach NOP Comment 6 was not adequately addressed is provided below.</u>

The study area extends to the intersection of the I-405 and I-605 freeway. It was not extended west to include SR-22 from the I-405 freeway to SR-1, per the City of Long Beach's request.

7. **The City of Long Beach respectfully requests that the study area be expanded on the I-605 freeway from the I-405 to Carson Street. It's possible that traffic currently using the I-405 could divert to the I-605 to avoid the bottleneck created thru the interchange.**

<u>This comment was not taken into consideration in the DEIR/EIS. Additional information regarding how the 2009 City of Long Beach NOP Comment 7 was not adequately addressed is provided below.</u>

The study area extends along I-605 to Katella Avenue. It was not extended north to Carson Street, per the City of Long Beach's request. Additional comments regarding the lack of appropriate level of analysis in Long Beach is provided in the detailed comments.

8. **The proposed project may create a potential significant impact in the form of substantial traffic disruption on streets within Long Beach during construction. Traffic mitigation may be required in Long Beach to accommodate additional traffic on arterial streets and to keep commuter traffic out of neighborhoods during the construction phase. The City of Long Beach respectfully requests that a preliminary Traffic Management Plan be developed as a part of the EIR process.**

<u>This comment was only partially addressed in the DEIR/EIS. Additional information regarding how the 2009 City of Long Beach NOP Comment 8 was not adequately addressed is provided below.</u>

A Draft Traffic Mitigation Plan (TMP) was prepared in accordance with the Caltrans Guidelines Deputy Directive 60 to minimize motorist delays when performing work activities on the State Highway System. The Draft I-405 Improvement Project TMP was prepared to present the overall framework for traffic management during construction. The Draft TMP includes general topics such as construction staging, closures and lane restrictions, demand management, alternate route strategies, and contingency plans, to name a few. Although the Draft TMP was prepared, it does not address traffic mitigation issues in the City of Long Beach.

I-405 Improvement Project DEIR/EIS – TECHNICAL COMMENTS

In addition to a review of the City's 2009 NOP comment letter, Iteris, Inc. also conducted a technical review of the complete environmental document as it pertains to traffic and other issues of interest to the City of Long Beach. The following provides a chapter-by-chapter summary of the technical comments and observations from the DEIR/EIS and its supporting documents. Note, the Traffic Study (Appendix L), the Draft Transportation Management Plan (TMP), and the Ramp Closure Study (RCS) are intermittently referenced throughout the technical review.

GL-9 (Continued)

ITERIS

I-405 Improvement Project DEIR/EIS Comments, July 17, 2012

I-405 Improvement Project DEIR/EIS: SUMMARY CHAPTER

1. **Project description includes the City of Long Beach, but the DEIR/EIS fails to conduct any technical analysis within the City.** As stated in the Project Description (p.S-2), "The approximately 16-mile-long project corridor is primarily located in Orange County on I-405 and traverses the cities of Cost Mesa, Fountain Valley, Huntington Beach, Westminster, Garden Grove, Seal Beach, Los Alamitos, ***Long Beach*** and the community of Rossmoor." The Project Description also describes the proposed project's limits as "...in Los Angeles County from the county line to 1.4 miles north of I-605 (p.S-2)." The project clearly acknowledges that the northern terminus of the project is located in the City of Long Beach. However, evaluation of the project clearly terminates at the Orange County/Los Angeles County line. The project description states, "Encroachments into Los Angeles County and work on SR-22 are associated with signing and striping (p.S-2)" only, and do not include any analysis in the City of Long Beach. <u>Missing analyses in Long Beach/Los Angeles County must be added to the document.</u>

2. **Project description acknowledges the intra/inter-regional significance of I-405, but the DEIR/EIS fails to conduct any technical analysis of I-405 through the City of Long Beach beyond the Orange County/Los Angeles County line.** As stated in the Project Description, "I-405 is part of the National Highway System and is considered a bypass route to I-5 (the Santa Ana/Golden State Freeway) providing intra-regional and inter-regional access between Orange and Los Angeles Counties. I-405 also serves as a critical goods movement corridor connecting the San Diego and U.S./Mexico border region with the ports of Long Beach and Los Angeles (p.S-3)." Despite these statements concluding the significance of I-405 as an intra/inter-regional corridor between Orange and Los Angeles County, no evaluation of I-405 north of the Orange/Los Angeles County line was conducted. An additional detailed review relating to this comment is provided under the discussion of Chapter 1, Proposed Project, Comment 3. <u>Missing analyses in Long Beach/Los Angeles County must be added to the document.</u>

3. **Project description states the northern terminus of the project (I-605) was chosen "to ensure adequate response to transportation deficiencies", but the "transportation deficiencies" along I-405 clearly don't end at I-605. As stated in the Project Description,** "the north and south termini of the project, at the I-605 and SR-73 respectively, are locations where multiple freeways converge, generating congestion and causing delay. The termini have been logically chosen based on geography and transportation needs to ensure adequate response to transportation deficiencies at and around these points of intersection (p.S-3)." The northern terminus of the proposed project is clearly based on the location of the Orange County/Los Angeles County line. The DEIR/EIS should take into consideration the effect of the proposed project on the adjacent segments of I-405, north of I-605 in Los Angeles County. An additional detailed review relating to this comment is provided under the discussion of Chapter 1, Proposed Project, Comment 5. The statements regarding beneficial effects on neighborhoods, even if correct, only would apply in the Orange County communities since no capacity enhancements are proposed in Long Beach. Within Long beach, the opposite effect could occur, and the possibility of impacts in Long Beach must be investigated. <u>Missing analysis of possible neighborhood impacts within Long Beach must be added.</u>

4. **The DEIR/EIS assumes the proposed project will result in a "beneficial effect on neighborhoods by reducing cut-through traffic" without providing any technical analysis or modeling results.** Table S-1 (Project Impact Summary Table) states under Community Impacts, Alternatives 1, 2 and 3, "Implementation of the proposed project is anticipated to result in a beneficial effect on neighborhoods and community cohesion by reducing cut-through traffic within the adjacent neighborhoods. At present, motorists traveling along I-405 often exit the freeway and seek less-congested alternative routes within the adjacent neighborhoods when freeway conditions deteriorate (p.S-14)." A discussion on how the analysis revealed that proposed project will result in a benefit to the community by reducing cut-through traffic in adjacent neighborhoods should be provided. An additional detailed response relating to this comment is provided under the discussion of Chapter 3.1, Section 3.1.4 Community Impacts, Comment 1. <u>Missing analysis of possible neighborhood impacts within Long Beach must be added.</u>

5. **The DEIR/EIS fails to provide a detailed analysis of how the additional anticipated 13 to 25 percent increase in vehicle throughput on I-405 will transition beyond I-605 through the City of Long Beach.** Table S-1 (Project Impact Summary Table) states under Traffic and Transportation/Pedestrian and Bicycle Facilities, Alternatives 1, 2 and 3, the proposed project will result in a permanent increase in vehicle throughput on the freeway by 13 to 25 percent between SR-22 East and I-605 (p.S-19). How will the additional throughput transition beyond the Orange County line into Los Angeles County? An additional detailed review relating to this comment is provided under the discussion of Chapter 2, Project Alternatives, Comment 1 and Chapter 3.1, Section 3.1.6 Traffic and Transportation/Pedestrian and Bicycle Facilities, Comment 4. <u>Missing analysis of impacts of added vehicle throughput in the City of Long Beach must be added.</u>

GL-9 (Continued)

ITERIS

I-405 Improvement Project DEIR/EIS Comments, July 17, 2012

I-405 Improvement Project DEIR/EIS: Chapter 1 – PROPOSED PROJECT

1. **Project map includes portions of the City of Long Beach, but the DEIR/EIS fails to conduct any technical analysis within the City.** According to Figure 1-2 (Project Location map), the proposed project area extends approximately one mile north of the Orange County/Los Angeles County line to Palo Verde Avenue in Los Angeles County and the City of Long Beach (p.1-3). While that study area presented extends into Long Beach, analysis was not performed for the proposed project area north of the Orange County/Los Angeles County line. Interchanges along I-405 north of the Orange County/Los Angeles County line should be evaluated, as well as arterial intersections in the City of Long Beach based on the Project Location map. An additional detailed review relating to this comment is provided under the discussion of Chapter 3.1, Section 3.1.6 Traffic and Transportation/Pedestrian and Bicycle Facilities, Comment 1. <u>Missing analysis in Long Beach must be added to the document.</u>

2. **2009 ADT volumes in the I-405 Improvement Project Traffic Study may have been underestimated near the City of Long Beach.** In the Capacity, Transportation Demand, and Safety section of Chapter 1 (p.1-6 to 1-8), 2009 traffic volumes were discussed. As stated in the footnote of Table 2.2.1 of the I-405 Improvement Project Traffic Study conducted by Albert Grover & Associates, existing 2009 ADT volumes were based on 2008 Caltrans published data, "*adjusted down by one percent in accordance with similar measured decreases throughout the area*" (p.2.2-1). However, Caltrans peak hour and AADT data was reviewed (Source: <u>http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/index.htm</u>) near the City of Long Beach and the data indicates that when 2008 and 2009 AADT volumes are compared on I-405 near the City of Long Beach, there is no measureable decrease in traffic volume between 2008 and 2009. Conversely, as shown in **Table 1** below, the Caltrans 2008 and 2009 data indicates a slight increase in traffic volumes (between 0.77 and 1.55 percent) during the peak hour, peak month, or for AADT. Adjusting the 2008 traffic volumes down by one percent to calculate existing 2009 traffic volumes may have underestimated the existing 2009 mainline, ramp and weaving level of service near the City of Long Beach. <u>The noted methodology must be reviewed and corrected, if required.</u>

Table 1: 2008 and 2009 Caltrans Traffic Volumes Near the City of Long Beach

District	Route	County	Post Mile	Description	Back Pk Hr	Back Pk Mo	Back AADT	Ahead Pk Hr	Ahead Pk Mo	Ahead AADT
2008										
12	405	ORA	22.643	SEAL BEACH, SEAL BEACH BLVD INTERCHANGE	26,500	381,000	374,000	26,500	392,000	386,000

GL-9 (Continued)

ITERIS

I-405 Improvement Project DEIR/EIS Comments, July 17, 2012

12	405	ORA	24.044	SEAL BEACH, JCT. RTE. 605	26,500	392,000	366,000	17,900	261,000	253,000
12	405	ORA	24.178	ORANGE LOS ANGELES COUNTY LINE	17,900	261,000	253,000			
07	405	LA	0.286	ORANGE/LOS ANGELES COUNTY LINE				18,300	258,000	253,000
07	405	LA	0.448	LONG BEACH, STUDEBAKER RD INTERCHANGE	18,300	258,000	253,000	16,900	265,000	261,000
07	405	LA	1.112	LONG BEACH, PALO VERDE AVE INTERCHANGE	16,900	265,000	261,000	17,100	258,000	254,000
2009										
12	405	ORA	22.643	SEAL BEACH, SEAL BEACH BLVD INTERCHANGE	26,500	381,000	374,000	26,500	392,000	366,000
12	405	ORA	24.044	SEAL BEACH, JCT. RTE. 605	26,500	392,000	358,000	18,100	263,000	255,000
12	405	ORA	24.178	ORANGE LOS ANGELES COUNTY LINE	18,100	263,000	255,000			
07	405	LA	0.266	ORANGE/LOS ANGELES COUNTY LINE				18,300	262,000	253,000
07	405	LA	0.448	LONG BEACH, STUDEBAKER RD INTERCHANGE	18,500	262,000	253,000	17,100	269,000	261,000
07	405	LA	1.112	LONG BEACH, PALO VERDE AVE INTERCHANGE	17,100	269,000	261,000	17,100	261,000	254,000
% Change										
12	405	ORA	22.643	SEAL BEACH, SEAL BEACH BLVD INTERCHANGE	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
12	405	ORA	24.044	SEAL BEACH, JCT. RTE. 605	0.00%	0.00%	0.00%	1.12%	0.77%	0.79%
12	405	ORA	24.178	ORANGE LOS ANGELES COUNTY LINE	1.12%	0.77%	0.79%			
07	405	LA	0.266	ORANGE/LOS ANGELES COUNTY LINE				1.09%	1.55%	0.00%
07	405	LA	0.448	LONG BEACH, STUDEBAKER RD INTERCHANGE	1.09%	1.55%	0.00%	1.18%	1.51%	0.00%
07	405	LA	1.112	LONG BEACH, PALO VERDE AVE INTERCHANGE	1.18%	1.51%	0.00%	1.17%	1.16%	0.00%

Source: Caltrans Traffic Volumes, 2008 and 2009.

3. **The DEIR/EIS fails to analyze any freeway segments or report any population/growth/employment projections in the City of Long Beach.** Under Section 1.2.2.5 (Modal Inter-Relationships and System Linkages), the DEIR/EIS states that "I-405 is part of the National Highway System and is considered a bypass route to I-5 (the Santa Ana/Golden State Freeway) providing intra-regional and inter-regional access between Orange and Los Angeles Counties (p.1-19)." The City of Long Beach is also listed as a "significant employment center" along the proposed project corridor (p.1-12), and the "northern segment (of I-405), between Valley View Street and the I-605, is considered one of the heaviest traveled sections of freeway in the nation (p. 1-20)." Despite these statements concluding the significance of I-405 as a heavily traveled regional access route, the DEIR/EIS fails to analyze any freeway segments or report any population/growth/employment projections within the proposed "project area" (theoretically I-405 to Palo Verde Avenue in the City of Long Beach) on I-405 in the City of Long Beach. Examples of tables in the DEIR/EIS that omit the City of Long Beach include:

    a. Table 1-2 and 1-3 (Existing and Projected 2020 and 2040 LOS and V/C Northbound and Southbound General Purpose Lanes);

    b. Table 1-4 (Existing and 2040 No Build Travel Time on I-405 from SR-73 to I-605 for Existing Condition and Year 2040 No Build Alternative);

    c. Table 1-6 Existing and Projected 2020 and 2040 Daily and Peak-Hour Traffic Volumes on I-405 within the Project Limits);

    d. Table 1-7 (Population Projections and Growth Trends), and

    e. Table 1-8 (Employment Projections and Growth Trends).

    Missing information and analysis in the City of Long Beach must be added to the document.

4. **The DEIR/EIS fails to explain how the added lanes associated with the proposed project on I-405 will transition beyond the Orange County line into Los Angeles County and the City of Long Beach.** Section 1.2.2.2, Roadway and Operational Deficiencies, states that "operation problems occur on I-405 primarily because of physical bottlenecks (p.1-14)". However, it remains unclear how the added lanes will transition beyond the Orange County line into Los Angeles County and the City of Long Beach. An additional detailed review relating to this comment is provided under the discussion of Chapter 2, Project Alternatives, Comment 1 and Chapter 3.1, Section 3.1.6 Traffic and Transportation/Pedestrian and Bicycle Facilities, Comment 4. Missing analysis of Impacts in the City of Long Beach, including traffic volumes, added lane transitions, traffic diversion, level of service and all other relevant issues must be added.

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5. **The DEIR/EIS fails to provide sufficient evidence supporting the claim that the proposed project would not result in a chokepoint north of I-605 in the City of Long Beach. In addition, the northern terminus of the proposed project does not meet the Logical Termini requirement of the FHWA.** Under the discussion of logical termini, the DEIR/EIS states with respect to the northern terminus, "the proposed additional lanes would enhance lane continuity along I-405 and terminate new lanes into available lanes on these other freeways (p.1-23)." The DEIS/EIS also states, "Carrying lanes north to the I-405/I-605/SR-22 interchange would not result in a chokepoint (p.1-24)." **If the proposed project's northern most study interchange is the I-405/I-605/SR-22 interchange, how was it determined that the proposed project alternatives would not result in a chokepoint north of the northern termini? The I-405/I-605/SR-22 Interchange does not seem like a "logical termini" for the northern segment of the I-405 Improvement Project.** Traffic should be further evaluated after the termination of the proposed project's additional lanes to ensure that a choke point does not occur north of the Orange County/Los Angeles County line in the City of Long Beach. The City of Long Beach does not feel that the northern terminus of the proposed project meets the "logical termini" requirement of the FHWA, as stated in the DEIR/EIS (p.1-24), thus resulting in an issue of "segmentation". The FHWA's discussion on logical termini and segmentation is provided below (The Development of Logical Project Termini, November 1993).

    "In developing a project concept which can be advanced through the stages of planning, environment, design, and construction, the project sponsor needs to consider a "whole" or integrated project. This project should satisfy an identified need, such as safety, rehabilitation, economic development, or capacity improvements, and should be considered in the context of the local area socioeconomics and topography, the future travel demand, and other infrastructure improvements in the area. Without framing a project in this way, proposed improvements may miss the mark by only peripherally satisfying the need or by causing unexpected side effects which require additional corrective action. A problem of "segmentation" may also occur where a transportation need extends throughout an entire corridor but environmental issues and transportation needs are inappropriately discussed for only a segment of the corridor."

    Missing analysis of impacts in the City of Long Beach, including traffic volumes, added lane transitions, traffic diversion, level of service and all other relevant issues must be added.

I-405 Improvement Project DEIR/EIS: Chapter 2 – PROJECT ALTERNATIVES

1. **The DEIR/EIS fails to provide an illustration of how the additional lanes associated with the proposed project on I-405 will transition beyond Orange County into Los Angeles County and the City of Long Beach.** Figures 2-1 and 2-2 (Lane Configurations, Northbound and Southbound) graphically illustrate the proposed lane configurations on I-405 between SR-73 and I-605 (p.2-6 and 2-7), but fail to show how the lanes will transition beyond Orange County into Los Angeles County. Proper evaluation of I-405 north of the Orange County/Los Angeles County line needs to be conducted to ensure that a choke point does not occur north of the Orange County/Los Angeles County line in the City of Long Beach. Missing analysis of Impacts in the City of Long Beach, including traffic volumes, added lane transitions, traffic diversion, level of service and all other relevant issues must be added.

2. **Alternative 2 lacks consistency with the current RTP and FTIP.** In the discussion of Alternative 2, the DEIR/EIS states that Alternative 2 is "considered a viable project alternative because it would achieve the

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project's purpose and need (p.2-10)." However, as stated in the Summary section of the DEIR/EIS, one of the proposed project's main purposes is to "be consistent with regional plans (p.S-1)." Table S-1 (Project Impact Summary Table) clearly states that Alternative 2 is "not consistent with the current RTP or FTIP. OCTA is currently pursuing revisions to both documents (p.S-13)." Discussion of the pursuit of Alternative 2's inclusion in the RTP or FTIP amendment should be discussed. Further coordination with regional plans and other regional and local planning agencies is required in order to assess the viability of this alternative.

3. **Alternative 3 lacks consistency with the current RTP and FTIP.** In the discussion of Alternative 3, the DEIR/EIS states that Alternative 3 is "considered a viable project alternative because it would achieve the project's purpose and need (p.2-14)." However, as stated in the Summary section of the DEIR/EIS, one of the proposed project's main purposes is to "be consistent with regional plans (p.S-1)." Table S-1 (Project Impact Summary Table) clearly states that Alternative 3 is "not consistent with the current RTP or FTIP. OCTA is currently pursuing revisions to both documents (p.S-13)." Further coordination with regional plans and other regional and local planning agencies is required in order to assess the viability of this alternative.

4. **The DEIR/EIS lacks consistency between its chapters with respect to anticipated ramp closures.** Table 2-1 (I-405 Improvement Project Alternatives Comparison) indicates that the northern-most ramp to be closed during construction is the Bolsa Chica Road southbound off-ramp (p.2-30). However, in Section 3.1.6, Traffic and Transportation/Pedestrian and Bicycle Facilities, it states that the southbound off-ramp at Seal Beach Boulevard will be closed between 10 and 30 days (p.3.1.6-106). Please confirm as the closure of the I-405 Seal Beach Boulevard southbound off-ramp will likely impact the City of Long Beach. Closure of a ramp for this duration warrants further evaluation of potential traffic impacts associated with detour routes. An additional detailed review relating to this comment is provided under the discussion of Chapter 3.1, Section 3.1.6 Traffic and Transportation/Pedestrian and Bicycle Facilities, Comment 9. Missing analysis of the potential ramp closure impacts on Long Beach must be added.

I-405 Improvement Project DEIR/EIS: Chapter 3.1 – Human Environment, Section 3.1.4 – COMMUNITY IMPACTS

1. **The DEIR/EIS assumes the proposed project will result in a "beneficial effect on neighborhoods by reducing cut-through traffic" without providing any technical analysis or modeling results.** Under the discussion of permanent Build Alternative impacts, the DEIR/EIS states that "implementation of the proposed project is anticipated to result in beneficial effects on community cohesion by reducing cut-through traffic within the adjacent neighborhoods. Currently, motorists traveling along I-405 often exit the facility and seek less congested alternative routes within the adjacent neighborhoods when freeway conditions deteriorate. Community members living within the vicinity of the I-405 corridor and people commuting between Los Angeles County and Orange County would benefit from the reduced congestion and the improved freeway operations (p. 3.1.4-19)". How was it determined that the proposed project would reduce cut-through traffic in adjacent neighborhoods? Is there empirical evidence (i.e. OCTAM modeling results, peak hour/AADT LOS, V/C analysis) supporting the reduction in cut-through traffic, specifically through the City of Long Beach? Please provide quantitative support that cut-through traffic exists and the magnitude of the cut-through activity. How will the cut-through activity be reduced through implementation of one of the proposed project alternatives? As future volumes increase through the corridor and level of service degrades, what is the impact on Long Beach due to cut-through traffic under future conditions? Additional explanation and supporting documentation of claims made regarding cut-through traffic must be added. Missing analysis of cut-through impacts in Long Beach must be added.

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I-405 Improvement Project DEIR/EIS: Chapter 3.1 – Human Environment, Section 3.1.6 – TRAFFIC AND TRANSPORTATION/PEDESTRIAN AND BICYCLE FACILITIES

1. **Project map includes portions of the City of Long Beach, but the DEIR/EIS fails to conduct any technical analysis within the City.** According to Figure 1-2 (Project Location map) in Chapter 1, Proposed Project, the proposed project area extends approximately one mile north of the Orange County/Los Angeles County line to Palo Verde Avenue in Los Angeles County and the City of Long Beach (p.1-3). However, in Section 3.1.6.2, Affected Environment, the traffic study area is defined as "16 miles along I-405 between SR-73 and I-605 (p.3.1.6-3)." As shown in Figure 3.1.6-1 (Traffic Study Area) (p.3.1.6-5), the study area does not include any interchanges on I-405 within Los Angeles County or the City of Long Beach. In addition, Table 3.1.6-1 lists the study intersections included in the DEIR/EIS (p.3.1.6-7 to 3.1.6-9), and no arterial intersections in the City of Long Beach were included in the analysis. Missing analysis of freeway and arterial intersections in the City of Long Beach must be added.

2. **The DEIR/EIS fails to provide an illustration of how the additional lanes associated with the proposed project on I-405 will transition beyond Orange County into Los Angeles County and the City of Long Beach.** Figures 3.1.6-3 and 3.1.6-4 (I-405 Lane Schematic, Northbound and Southbound) graphically illustrate the proposed lane configurations on I-405 between SR-73 and I-605 (p.3.1.6-16 and 3.1.6-17). Same comment as Chapter 2, Project Alternatives, Comment 1. Missing analysis of impacts in the City of Long Beach, including traffic volumes, added lane transitions, traffic diversion, level of service and all other relevant issues must be added.

3. **2009 ADT volumes in the I-405 Improvement Project Traffic Study may have been underestimated near the City of Long Beach.** The freeway mainline discussion used Caltrans-published traffic data from the Caltrans website to calculate their 2009 freeway volumes (p.3.1.6-21). 2009 traffic volumes are also shown in Table 3.1.6-2 (I-405 Mainline Average Daily Traffic) (p.3.1.6-22). Same comment as Chapter 1, Proposed project, Comment 2. The noted methodology must be reviewed and corrected if required.

4. **The DEIR/EIS fails to provide a detailed analysis of how the additional anticipated increase in vehicle throughput associated with the project alternatives will transition beyond I-605 through the City of Long Beach.** Table 3.1.6-2 (I-405 Mainline Average Daily Traffic) shows that the proposed alternatives have the potential to increase the mainline ADT up to 142,000 additional daily vehicles (28 to 38 percent increase) beyond existing 2009 conditions on I-405 between SR-22 East and I-605 by 2040 (see **Table 2A**). Similarly, Table 3.1.6-2 also shows that the proposed alternatives have the potential to generate up to 108,000 additional daily vehicles (18 to 27 percent increase) beyond the No Build scenario on I-405 between SR-22 East and I-605 by 2040 (see **Table 2B**). It is unclear how the increase in vehicle throughput will be addressed north of the Orange County/Los Angeles County line (specifically in the City of Long Beach) after the proposed project ends. Additional impact analyses need to be evaluated in Los Angeles County and in the City of Long Beach to address the increase in throughput associated with the proposed project alternatives, and the potential for chokepoints and traffic diversion onto adjacent freeways and arterials.

Table 2A: 2009 vs. Alternatives

Segment		2020				2040			
	2009	No Build	Alt 1	Alt 2	Alt 3	NB	Alt 1	Alt 2	Alt 3
SR-22 East to I-605 [1]	370,000	404,000	433,000	453,000	455,000	427,000	475,000	509,000	512,000
Increase in ADT over 2009		34,000	63,000	83,000	85,000	57,000	105,000	139,000	142,000
Percent Increase over 2009		9%	17%	22%	23%	15%	28%	38%	38%

[1] Source: Table 3.1.6-2, I-405 Mainline Average Daily Traffic, p. 3.1.6-22

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Table 2B: No Build vs. Alternatives

Segment		2020				2040			
	2009	No Build	Alt 1	Alt 2	Alt 3	NB	Alt 1	Alt 2	Alt 3
SR-22 East to I-605 [1]	370,000	404,000	433,000	453,000	456,000	427,000	475,000	509,000	512,000
Increase in ADT over No Build			29,000	49,000	51,000	23,000	71,000	105,000	108,000
Percent Increase over No Build			7%	12%	13%	6%	18%	26%	27%

[1] Source: Table 3.1.6-2, I-405 Mainline Average Daily Traffic, p. 3.1.6-22

Missing analysis of impacts in the City of Long Beach, including traffic volumes, added lane transitions, traffic diversion, level of service and all other relevant issues must be added.

5. As discussed in the DEIR/EIS Traffic Forecasting Model discussion, "A single demand forecast was prepared for the proposed project area. Freeway mainline forecasts for each of the alternatives utilize the same total traffic volumes on a segment but redistribute volumes among the different lane types, as necessary (p.3.1.6-39)." It also states that, "Because of a very small variation in projected traffic volumes during the peak hours at the freeway interchanges among the three proposed project alternatives, it was jointly agreed by Caltrans, OCTA, and the Project Consulting Team that only one set of future traffic volumes would be used for analyzing the proposed project condition on the arterials (p.3.1.6-39)." The following comments are related to the aforementioned assumptions:

   a. **The DEIR/EIS assumes travel demand is fixed through the corridor, irrespective of actual corridor capacity.** The traffic study indicates that OCTAM was applied to generate future forecast volumes for the corridor. However, it has been noted that one future model run was prepared to generate future corridor forecast volumes and the traffic volumes were distributed across the various lane assumptions for each alternative. This approach is flawed in that it assumes travel demand is fixed through the corridor and irrespective of actual corridor capacity. Which future scenario was run with OCTAM to determine corridor travel demand and how was that determination made?

   b. **The DEIR/EIS should provide further justification for using a single forecast to develop future forecast volumes.** Application of OCTAM for other congested corridors in Orange County has revealed a sensitivity to capacity with traffic demand varying based on the amount (i.e. number of lanes) and type (general purpose, HOV, toll) of capacity provided. For the congested I-405 corridor, Table 3.1.6-12 reveals that every segment of I-405 is significantly over capacity for each proposed project alternative (p.3.1.6-73). With congestion levels of this magnitude, OCTAM would be expected to generate different levels of traffic demand for each proposed project alternative which would result in a more appropriate comparative analysis between the proposed project alternatives. It is not understood, nor explained, how a single forecast model run could generate the demand volumes for the various future project alternatives. Justification for using a single forecast to develop future forecast volumes should be provided. OCTAM has been applied to evaluate various HOV, toll and express lane projects throughout the County; why would it not be applied for each alternative?

   c. **The DEIR/EIS should provide clear documentation of future year model network assumptions.** Future year model assumptions that were applied to generate the future corridor traffic volumes are not clearly defined. The recently adopted Regional Transportation Plan includes Express Lanes on I-405 in Los Angeles County and the traffic study does not clearly define network assumptions incorporated into the model run that was performed to generate the future forecasts. The alternative lane schematics seem to indicate that Express Lanes were not assumed in Los Angeles County. Regional projects could impact traffic demand on I-405 including capacity on I-5 in Orange and Los Angeles County, Express Lanes on I-405 in Los Angeles County, implementation of High Speed Rail and other regional multi-modal projects. It has been noted

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elsewhere in the document that I-405 serves as a bypass route to I-5 (the Santa Ana/Golden State Freeway) providing intra-regional and inter-regional access between Orange and Los Angeles Counties and as such improvements to I-5 would impact I-405 traffic demand. Clear documentation of future year model network assumptions based on the adopted Regional Transportation Plan should be provided to appropriately assess future forecast volumes.

   d. **Clarification should be provided documenting why a 2020 scenario was not modeled directly to generate the opening year volumes.** Year 2020 traffic volumes were interpolated from the 2009 and 2040 forecast volumes. Clarification should be provided as to why a 2020 scenario was not modeled directly to generate the opening year volumes. As noted in the study, the OCTAM horizon year is 2035 and post-processing was applied to generate 2040 forecasts. Since 2040 is a post-processed volume, why would the interpolation not be performed between 2009 and the actual model horizon year of 2035 to generate a more accurate interim year forecast volume if a 2020 scenario is not directly modeled? Interpolating volumes for a corridor of this magnitude may not provide accurate results as interpolation does not appropriately consider network assumptions and timing of those infrastructure improvements that may impact forecast volumes. Consistent with the 2040 forecast volumes, corridor capacity assumptions for the alternatives would likely result in varying levels of demand across alternatives. Forecasts for Alternative 3 are suspect since the Express Lane volumes appear to be rounded to 100's while HOV volumes for all alternatives along with mainline volumes are presented as exact numbers with no rounding. The rounded Express Lane volumes appear inconsistent with the methodology applied to generate the volumes for the other alternatives.

   e. **High future forecast volumes in the City of Long Beach raise concerns regarding future traffic operations. Traffic should be evaluated north of the Orange County/Los Angeles County line.** The magnitude of future forecast volumes approaching the City of Long Beach are very high, thus concerns exist about how the future forecast volumes are generated and ultimately impact traffic operations in and through the City of Long Beach.

A significant amount of information is missing and must be provided in the sections of the EIR/EIS describing the traffic modeling methodology and results. Missing information relating to several key modeling issues must be provided. Much more detailed information describing how one future model run could adequately capture future travel, what would be the differences in corridor travel demand and travel demand in Long Beach if OCTAM was run with the actual alternatives coded in the model, what would be the differences if a 2020 model run was conducted versus "interpolating" model results, what would the resulting travel demand be if Express Lanes were coded into the model within Orange County as well as within Los Angeles County, and other similar issues.

6. **The DEIR/EIS lacks a sufficient discussion regarding the travel demand forecasts assumptions under Alternative 3.** As discussed under Alternative 3, the travel demand forecasts for Alternative 3 use the same travel demand forecasts as the other alternatives. No discussion is provided regarding the effect that toll lanes may have on the travel demand in the study area, nor outside of the study area into the City of Long Beach and Los Angeles County. Recent work undertaken in the City of Long Beach and the Gateway Cities reveals that tolling assumptions can have a significant impact on travel demand forecasts and allocation of traffic among the types of lanes on the facility. In addition, coordination of assumptions across county lines is critical to this analysis. For example, assumptions such as peak/off-peak tolling rates and the decision to charge or not charge vehicles with various vehicle occupancy thresholds (such as 3+ carpools) can significantly affect the results in terms of Express Lane usage. The amount of demand in the Express Lanes not only affects the corridor under study but also could significantly affect local arterials and the State Highway System in the City of Long Beach. As of now, there is not a consistent policy regarding how to handle Express Lane toll rates and operations across county lines. All of these issues

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are ignored within the traffic study and the resulting travel demand and associated analysis could be significantly affected. Discussion of these issues must be included in the analysis of Alternative 3 along with detailed analysis of the affects that the tolling will have on travel demand and operations into the City of Long Beach on both I-405 and I-605. The following important questions are raised:

a. What happens if the proposed project is built but the Express Lanes are not continued into Los Angeles County?

b. How would the lanes transition and operate in the City of Long Beach if the proposed project is built?

c. Metro is currently considering Express Lanes on I-405 in Los Angeles County. What happens if the proposed project is built and the Express Lanes are carried into the City of Long Beach and Los Angeles County? How would that not only affect freeways in Los Angeles County, but how would that affect the travel forecasts for the proposed project in Orange County as well? With the modeling conducted as described, there is no way to understand the variation in the proposed project area volumes that would occur under these scenarios and thus the EIR does not disclose the true impacts of the proposed project either in the study are nor in the area that should have additionally been studied in the City of Long Beach.

d. What types of coordination would be required and how would the lanes operate, specifically as a result of implementing the proposed project?

e. What are the differences in travel demand in the City of Long Beach for the scenarios with and without Express Lanes carried across the county line?

<u>Significant additional information and analysis is required to understand potential impacts of the alternatives in both Orange County as well as into Long Beach. Model run tests are needed to test impacts of alternative scenarios in the project area as well as in the missing affected areas in Long Beach. It is appropriate to test potential extensions of Express Lanes into Los Angeles County, as well as if Express Lanes were ended at the county line. If Express lanes are not extended into Los Angeles County, significant additional analysis of operational and geometric issues in Long Beach must be included so that there is documentation of potential impacts in Long Beach under all alternatives, with and without Express Lanes.</u>

7. **The DEIR/EIS lacks analysis regarding possible increases the general purpose lanes or diversion to other routes in the City of Long Beach due to increased congestion.** It is known that Express Lanes will likely result in some shifting of traffic from the Express Lanes (prior HOV lanes) to the General Purpose lanes. This could either increase the general purpose lane volume in the City of Long Beach, or result in diversion to other routes in the City of Long Beach due to increased congestion in the general purpose lanes, or both. These possible significant impacts have not been considered or analyzed in the traffic study. <u>Missing information on Express Lane impacts on the freeway system must be added.</u>

8. **The DEIR/EIS fails to provide details regarding the transition area beyond the Orange County line into Los Angeles County and the City of Long Beach.** Table 3.1.6-17 (Transition Area LOS) summarizes the AM and PM LOS in each of the transition areas anticipated in 2020 and 2040 under Alternative 3 and No Build (p.3.1.6-97). However, no transition areas were evaluated on I-405 north of the I-605/I-405/SR-22 intersection in Los Angeles County or the City of Long Beach. <u>Missing information and analysis of impacts in the City of Long Beach must be added.</u>

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9. **The DEIR/EIS lacks consistency between its chapters and associated reports with respect to anticipated ramp closures.** As discussed under Temporary Build Alternative Impacts (p. 3.1.6-106), the I-405 southbound off-ramp at Seal Beach Boulevard is expected to be closed between 10 to 30 days during construction. Closure of the Seal Beach Boulevard off-ramp will likely result in cut-through traffic in the City of Long Beach. The DEIR/EIS for the proposed project states that tentative detours for the ramp closures are identified in the Ramp Closure Study (RCS) (Appendix C of the Community Impact Assessment). When the RCS was reviewed, Table 1 (Local Service Interchange Ramps and Anticipated Closure within the I-405 Improvement Project) indicated that the Seal Beach Boulevard southbound off-ramp has an AADT of 10,500 and will be closed for up to 30 days. However, in the "Description of Prolonged Closure Sites and Proposed Detour Route" section of the RCS, all ramps with anticipated long-term ramp closures (10 or more days) were listed and described in detail, with the exception of the Seal Beach Boulevard southbound ramp. The "Bolsa Chica Road Southbound Off-Ramp" was described where the "Seal Beach Boulevard Southbound Off-Ramp" description should have been. The alternate route maps in the report's attachment also omit the Seal Beach Boulevard Southbound Off-Ramp. This is a noteworthy discrepancy because closure of the Seal Beach Boulevard southbound off-ramp could significantly impact construction-related traffic in and around alternate I-405 ramps and adjacent arterials in the City of Long Beach.

a. The "Ramp Closure" list in the Transportation Management Plan (TMP) for the proposed project is also inconsistent with the DEIR/EIS and Table 1 of the RCS. The DEIR/EIS and Table 1 of the RCS indicate that the southbound off-ramp at Seal Beach Boulevard will be closed for up to 30 days and the list of ramp closures from the TMP (p.11) indicates that Bolsa Chica Road southbound off-ramp will be closed.

<u>Missing analysis of potential ramp closures in Long Beach must be added.</u>

I-405 Improvement Project DEIR/EIS: Chapter 3.6 – CUMULATIVE IMPACTS

1. **The DEIR/EIS fails to analyze the cumulative impact of future growth in the City of Long Beach.** As discussed in Section 3.6.2 of the Cumulative Impact section, Methodology, future growth was considered within "the Cities of Costa Mesa, Fountain Valley, Garden Grove, Huntington Beach, Los Alamitos, Westminster, and Seal Beach as well as the County of Orange unincorporated community of Rossmoor (p.3.6-2)." The list of cities and unincorporated areas included in the cumulative analysis includes all of the cities and areas listed in the proposed Project Description (p.S-2) in the DEIR/EIS Summary, with the exception of the City of Long Beach. The growth in City of Long Beach should be included in the proposed project's cumulative analysis. The proposed project description in the DEIR/EIS Summary is as follows:

> *"The approximately 16-mile-long project corridor is primarily located in Orange County on I-405 and traverses the cities of Cost Mesa, Fountain Valley, Huntington Beach, Westminster, Garden Grove, Seal Beach, Los Alamitos, Long Beach and the community of Rossmoor."*

<u>Missing cumulative analysis must be added.</u>

This concludes our summary of comments on the EIR/EIR documents. There are likely other comments that will be appropriate following receipt of responses. Please let us know if you have any questions or concerns. Iteris, Inc. would be happy to meet with City staff to discuss the results of the review and technical memorandum.

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ITERIS

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Sincerely,

Gary Hamrick
Vice President
Transportation Systems
Iteris, Inc.

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Attachment 5

Kenneth A. Small and Chen Feng Ng
Optimizing Road Capacity and Type
June 1, 2013

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GL-9 (Continued)

Optimizing Road Capacity and Type

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June 1, 2013

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Keywords: Capacity, free-flow speed, highway design, optimal highway investment, congestion
JEL codes: L91, R42

Abstract

We extend the traditional road investment model, with its focus on capacity and congestion as measures of capital and its utilization, to include free-flow speed as another dimension of capital. This has practical importance because one can view free-flow speed as a continuous proxy for road type (e.g. freeway, arterial, urban street). We derive conditions for optimal investment in capacity and free-flow speed, and analyze the optimal balance between the two. We then estimate cost functions for capital and user costs and apply the resulting model using parameters representing large US urban areas. We show that providing high free-flow speed may be quite expensive, and there is sometimes a tradeoff between it and capacity. We find suggestive evidence that representative freeways in most large urban areas provide too high a free-flow speed relative to capacity, thus making the case for reexamination of typical design practice.

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Optimizing Road Capacity and Type

Kenneth A. Small
Chen Feng Ng

1. Introduction

The economic analysis of congestion and investment in road capacity is well developed. The research literature contains an abundance of optimality conditions, implications for pricing, and policy implications including such practical matters as second-best pricing, investment under conditions of suboptimal pricing, and financial balance between pricing revenues and investment costs.[1] In such analyses, roads are generally taken to be sufficiently characterized by a single dimension, capacity, with other issues such as safety or aesthetic ride quality dealt with as separate side issues.[2] In part, this emphasis is justified by the apparent dominance of congestion among the costs of urban road trips.[3]

Yet some of the most serious practical issues in road policy involve other aspects of roads such as their safety, environmental impacts, aesthetics, and impacts on neighborhoods and other considerations of urban design. As a result, passionate debates arise about not only the amount of road space to provide, but its type. In particular, the penetration of dense urban development by high-speed and high-capacity expressways has always been controversial.

Transportation economists have had less to say about these latter issues, and a major reason is the single capital dimension in the standard economic models of road investment. Yet it is entirely possible to build very different looking urban road networks of equal capacities, one using high-speed freeways and another using well-engineered arterials. These design tradeoffs require other measures of road capital than capacity.

The goal of this paper is to provide an expanded investment model that lends itself to analyzing such issues, by including free-flow speed as an additional design variable describing road capital. While naturally not every issue of interest can be captured with just one additional

[1] Examples include Mohring and Harwitz (1962), Strotz (1965), Keeler and Small (1977), and Jansson (1984). For reviews see Lindsey and Verhoef (2000) and Small and Verhoef (2007, ch. 5).

[2] In two cases, however, these other road characteristics are explicitly modeled either as a type of scale economy (Jansson 1984, ch. 10) or as a quality variable (Larsen 1993).

[3] Small and Verhoef (2007), sect. 3.4.6.

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variable, the advantages of tractability and transparency make this an attractive way to begin bringing the analysis of road types into mainstream transportation economics.

To implement the model, we use empirical data to estimate both investment costs and user costs as functions of the two design variables (capacity and free-flow speed). We estimate a construction-cost function using data on costs of various road types along with their free-flow speeds and capacities. We estimate a user-cost function from information about speeds and flows of different road types, differentiated by free-flow speed,[4] which we supplement with a queuing analysis to account for situations where input flow exceeds capacity.

The result is a continuous, differentiable total cost function which permits standard investment analysis. The model produces the familiar criterion for incremental investment in capacity, and a new criterion for incremental investment in free-flow speed. We combine these criteria to examine how to recognize under what conditions a given road is well balanced between these two dimensions: i.e., when does a given road design provide too high or low a free-flow speed relative to its capacity? We examine this balance condition for 24 standard road types under hypothetical conditions, and for representative freeways and arterials for 47 US urban areas under actual conditions.

While our goal here is not primarily policy analysis, the model does permit another look at a question considered by Ng and Small (2012). Given that many high-speed urban expressways operate under severe congestion for several hours each day, is the extra expense of providing such high-speed service under more moderate traffic justified? In the extreme case where all traffic occurred during a peak period impacted by queues behind fixed-capacity bottlenecks, there would be no advantage to high free-flow speed. In more realistic cases, there are tradeoffs involving the duration of peak periods and the relative traffic volumes in peak and off-peak periods. Our earlier paper considers this question by comparing a few specific road types chosen to illustrate the tradeoff between free-flow speed and capacity, or between free-flow speed and construction cost. Here, we develop a more general model of road investment where both capital costs and user costs can vary depending on free-flow speed and capacity, each of which lies along a continuum.

[4] Such information is compiled in the Highway Capacity Manual (Transportation Research Board 2000) from decades of engineering research.

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We do find some evidence that typical freeways in large urban areas are over-designed for free-flow speed at the expense of capacity. This arises largely from the finding that the cost elasticity for increasing free-flow speed is, on average, more than three times that for expanding capacity (roughly 1.4 vs. 0.4); as a result even modest amounts of congestion favor incremental investments in capacity relative to free-flow speed. While the optimal road configuration is very case-specific, we can state a more general policy conclusion: road design needs to allow for variety and flexibility, rather than being constrained to meet a predetermined set of standards such as those for US Interstate Highways. There are probably many situations where urban areas are well served by parkways, high-type arterials, or urban streets with well-engineered intersections as a means of carrying large traffic flows efficiently.

2. Long-run cost functions with two dimensions of infrastructure

Total costs of road travel in our model consist of amortized capital cost and user costs. We adopt simple formulations for each, in order to emphasize what is new in this paper, namely the role of free-flow speed as a design variable. Thus, for example, we ignore road maintenance costs (assuming they would not affect design), accident costs (as there is mixed evidence in the literature regarding the impact of design speed on accident rates),[5] other user costs aside from time (assuming they are proportional to vehicle flow and therefore also do not affect design), and environmental costs (which are best dealt with using other tools).

Annualized capital cost is composed of initial costs of structures and land, each amortized at a constant rate over its lifetime. These costs depend on road design via the variables measuring capacity and free-flow speed:

$$\rho(V_K, S_f) = \frac{r}{1-e^{-r\Lambda}} K(V_K, S_f) + rA(V_K, S_f) \qquad (1)$$

where V_K and S_f are design capacity and free-flow design speed, respectively, K is construction cost, A is right-of-way acquisition cost, r is the interest rate, and Λ is the road life in years, i.e.

[5] As discussed in Ng and Small (2012), some of the design features that could result in lower free-flow speeds (like narrower lanes or a lower type of road such as a highway instead of a freeway) do not necessarily lead to higher accident rates, especially if the roads are accompanied by lower speed limits.

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the time after which the structures and improvements (but not the land) have lost all their value. We assume that K and A are increasing in both V_K and S_f. This formulation assumes the annualized cost is constant over the road's lifetime.

Total user cost U_t during time interval t consists solely of time costs measured at a constant value of time, α. User time depends both on free-flow speed and on congestion, the latter via the volume-capacity ratio:

$$U_t(V_t \mid V_K, S_f) = V_t c_t = V_t \frac{\alpha}{S_t\left(\frac{V_t}{V_K}, S_f\right)} \qquad (2)$$

where t is a time interval (of duration q_t), V_t is traffic volume, c_t is average user time cost, and S_t is average speed. The latter is assumed to be increasing in S_f, and to be decreasing and concave in volume-capacity ratio.

The short-run total cost function, including agency costs, is therefore:

$$C(V \mid V_K, S_f) = \rho(V_K, S_f) + \sum_t q_t U_t(V_t \mid V_K, S_f)$$
$$= \frac{r}{1-e^{-r\Lambda}} K(V_K, S_f) + rA(V_K, S_f) + \alpha \sum_t \frac{q_t V_t}{S_t\left(\frac{V_t}{V_K}, S_f\right)} \qquad (3)$$

where $V=\{V_t\}$ is the time pattern of vehicle flows.

The long-run cost function is obtained by choosing the design variables so as to minimize short-run total cost:

$$\tilde{C}(V) = \min_{V_K, S_0} C(V \mid V_K, S_f)$$
$$= \min_{V_K, S_f} \left[\rho(V_K, S_f) + \alpha \sum_t \frac{q_t V_t}{S_t\left(\frac{V_t}{V_K}, S_f\right)} \right].$$

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The conditions for this minimization constitute the investment rules governing capacity and free-flow speed. Assuming interior solutions, they are:

$$\frac{\partial \rho}{\partial V_K} = -\sum_t q_t V_t \frac{\partial c_t}{\partial V_K} \tag{4a}$$

$$\frac{\partial \rho}{\partial S_f} = -\sum_t q_t V_t \frac{\partial c_t}{\partial S_f} \tag{4b}$$

which state that each type of investment should be undertaken to the point where the resulting marginal saving in user cost equals its incremental annualized capital cost. The first of these investment rules is standard.[6] The second is new to this paper, but obviously follows the same logic.

Equations (4a) and (4b) may be simplified by taking advantage of our assumption that user cost is a function of volume and capacity only through their ratio, an assumption which also underlies the analysis of self-financing by Mohring and Harwitz (1962, pp. 84-87).[7] This assumption implies that

$$V_K \frac{\partial c_t}{\partial V_K} = -V_t \frac{\partial c_t}{\partial V_t}$$

from which we can rewrite (4a) and (4b) in elasticity terms as:

$$\varepsilon_{\rho,VK} = \frac{1}{\rho}\sum_t q_t V_t \cdot (mecc)_t = \frac{\widetilde{R}}{\rho} \tag{5a}$$

[6] This investment rule is given in various forms by Mohring and Harwitz (1962, p. 84), Strotz (1965, eq. 1.17), and Keeler and Small (1977), eq (5). See Small and Verhoef (2007, eq. 5.3) for a concise derivation.

[7] This assumption is sometimes described as constant returns to scale in congestion technology: see Small and Verhoef (2007, p. 165).

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$$\varepsilon_{\rho,Sf} = \frac{1}{\rho}\sum_t q_t V_t c_t \cdot \left(\varepsilon_{S,Sf}\right)_t \tag{5b}$$

where $(mecc)_t \equiv V_t(\partial c_t/\partial V_t)$ is the marginal external congestion cost of a trip, $\varepsilon_{\rho,VK}$ and $\varepsilon_{\rho,Sf}$ are the elasticities of annualized capital cost with respect to capacity and free-flow speed, respectively, and $\varepsilon_{S,Sf}$ is the elasticity of the function $S(\cdot)$ with respect to S_f. (This last elasticity may vary by time period.) The quantity $\widetilde{R}$ is imputed revenues from a hypothetical congestion toll set equal to $mecc_t$ in each period when traffic is given by vector V.[8] Therefore (5a) expresses the self-financing theorem, which states that annual revenues from such a toll would equal annualized capital costs times the cost elasticity of capital cost with respect to V_K. Equation (5b) has no comparable interpretation, since there is no efficiency reason to impose a toll for free-flow speed.

The quantities in equations (5a) and (5b) are likely to be quite case-specific, making it difficult to draw general conclusions from these investment criteria. However, we are more confident in their ratio, which is based on the relative costs of the two kinds of investment and the relative cost savings they provide to users. Therefore, we primarily consider what we call "investment balance," defined by dividing (5a) by (5b):

$$\frac{\varepsilon_{\rho,VK}}{\varepsilon_{\rho,Sf}} = \frac{\widetilde{R}}{\sum_t q_t V_t c_t \cdot \left(\varepsilon_{S,Sf}\right)_t} \equiv \frac{\sum_t q_t V_t \cdot (mecc)_t}{\sum_t q_t V_t c_t \cdot \left(\varepsilon_{S,Sf}\right)_t}. \tag{5c}$$

This implication of the first-order conditions makes clear that if congestion is large, so that *mecc* exceeds $c \cdot \varepsilon_{S,Sf}$ for a large portion of the time, investment in capacity will be favored relative to that in free-flow speed. On the other hand, if peak traffic congestion is not severe and off-peak travel is extensive, the ratio on the right-hand side will tend to be small, favoring investment in free-flow speed. In what follows, we refer to the left-hand side (LHS) of equation (5c) as the "ratio of construction cost elasticities," and the right-hand side (RHS) as the "ratio of marginal user costs" (i.e., the ratio of incremental user-cost savings from expanding capacity versus

[8] As is well known, such a toll can be derived by maximizing the difference between consumers' valuation of their travel (the area under their inverse demand curve) and total costs. See Keeler and Small (1977).

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increasing free-flow speed). Our measure of "investment balance" is LHS – RHS; a positive number means that marginal investment in S_f is favored relative to that in V_K.

Intuition is aided by an example. First, suppose travel time is given by the free-flow travel time plus a queuing time applicable only if capacity is exceeded:

$$\frac{1}{S} = \frac{1}{S_f} + \max\left[\frac{q_t}{2} \cdot \left(\frac{V_t}{V_K} - 1\right), 0\right]. \tag{6}$$

This piecewise-linear cost function describes the time-averaged user cost for a deterministic bottleneck of constant capacity, assuming there is no queue at the beginning of the time period. We then have $mecc = \alpha \cdot [(1/S) - (1/S_f)]$, $\varepsilon_{S,Sf} = S/S_f$, and the first-order investment conditions are:

$$\varepsilon_{\rho,VK} = \frac{U^g}{\rho}; \qquad \varepsilon_{\rho,Sf} = \frac{U^0}{\rho} \qquad \Rightarrow \qquad \frac{\varepsilon_{\rho,VK}}{\varepsilon_{\rho,Sf}} = \frac{U^g}{U^0} \tag{7}$$

where total user cost U over all time periods has been divided into that due to free-flow travel time, $U^0 \equiv \alpha \sum_t q_t V_t / S_f$, and that due to congestion, $U^g \equiv U\text{-}U^0$. This example makes clear that a marginal increase in capacity is valuable when user costs of congestion (U^g) are high, whereas an increase in free-flow speed is valuable when user costs of free-flow travel (U^0) are high.[9]

With more realistic models of speed determination, the more general equations (5) can be used to assess current or proposed planning for road capacity and type. A hypothesis motivating this paper is that current planning guidelines for urban areas may place too much emphasis on free-flow speed relative to capacity. This could take the form either of designing a give type of roadway for unnecessarily high speeds, or of choosing a higher type of roadway than necessary. Empirical measurements suggesting that the cost ratio on the right-hand side of (5c) exceeds the elasticity ratio on its left-hand side would provide evidence for this hypothesis.

[9] Another example is when time spent in congestion is modeled, as is common, as a power function of the volume-capacity ratio with power b. Then $mecc = \alpha b \cdot [(1/S) - (1/S_f)]$ and $\varepsilon_{S,Sf} = 1$; the optimization conditions are $\varepsilon_{\rho,VK} = bU^g/\rho$ and $\varepsilon_{\rho,Sf} = U/\rho$. In this case cost added by congestion is affected by S_f, which is why the numerator of the second equation includes total user cost U and not just the uncongested portion U^0 as it did in the other example.

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Alternatively, one can consider the tradeoff between free-flow speed and capacity inherent in any particular set of incremental plans or planning guidelines by rewriting (5c) as:

$$\left(-\frac{dS_f / S_f}{dV_K / V_K}\right)_\rho = \frac{\widetilde{R}}{\sum_t q_t V_t c_t \cdot (\varepsilon_{S,Sf})_t}. \tag{5c'}$$

Suppose, for example, a particular road design could be modified at no change in cost so as to increase free-flow speed 2 percent by sacrificing one percent of capacity. This change would be beneficial if the ratio on the right-hand side of (5c′) (computed with the proposed design in place) is less than 2, whereas a trade in the opposite direction would be beneficial if that ratio is greater than 2. As a reminder, all these types of statements presume that there is a continuum of possible designs and that the resulting costs are smooth functions.

3. Empirical estimation of cost functions

3.1 Data for costs, free-flow speeds, and capacities

We wish to estimate construction costs as a function of capacity and free-flow speed, while holding constant other factors such as terrain, climate, and input prices. Since we are more interested in the relative costs of different types of roads than their absolute costs, we are not too concerned about whether we have representative values for those other factors, but do want detailed differences among road types. Such data are provided by the Specifications and Estimates Office of the Florida Department of Transportation (FDOT). These data contain estimated quantities and prices of inputs needed for various types of roads in urban areas, while holding other factors constant.

The basic data, shown in Table 1, tell us about the tradeoffs among alternative road designs discussed in previous sections. For example, as we shall see shortly, a 4-lane divided urban street has the same free-flow speed as an undivided 5-lane urban street with a center turn lane, but the former costs more and has higher capacity. Meanwhile a 4-lane Interstate offers greater free-flow speed but lower capacity than a 6-lane multilane highway, with only a small

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cost difference. Thus, capacity and free-flow speed show sufficient independent variation that we expect to see some possibilities for substitution of the type highlighted in equation (5c').

Table 1. FDOT cost estimates (in 2011 prices)

Description	No. lanes	Bike lane (width)	Median (width)	Shoulders (inside & outside)	Cost per mile (mill. $)
Undivided arterial	2	4 ft	---	---	4.794
Undivided arterial with center lane	3	4 ft	---	---	4.769
Undivided arterial	4	4 ft	---	---	5.132
Undivided arterial with center lane	5	4 ft	---	---	5.814
Divided arterial	4	4 ft	22 ft	---	7.123
Divided arterial	6	4 ft	22 ft	---	7.986
Divided Interstate, closed median with barrier wall	4	---	22 ft	10 ft	8.875
Divided Interstate, closed median with barrier wall	6	---	22 ft	10 ft	9.858

Source: Statewide cost estimates published in January 2012 by the Specifications and Estimates Office of the Florida Department of Transportation (http://www.dot.state.fl.us/specificationsoffice/).

These cost estimates are even more useful because they contain detailed information on individual components such as embankment, pavement, pipe culverts, lighting, etc. This additional information enables us to double our sample size by estimating, for each road type, the cost of an otherwise identical road but with 11-foot lanes instead of the default lane width of 12 feet. This is done by reducing the relevant costs (embankment, stabilization and pavement costs) proportionately, while keeping other costs (such as the costs of pipe culverts, curbs and gutters, pavement markings, lighting and signage) constant. Since 11-foot lanes are recognized in the Highway Capacity Manual (HCM) (Transportation Research Board 2000), we will be able to measure the deterioration of service quality and capacity that accompanies the lower costs and, as we shall see, these two dimensions are not degraded proportionally.

In order to calculate free-flow speeds and capacities for each road type, we use the 2000 Highway Capacity Manual, supplemented where necessary by the FDOT road descriptions and HCM default values; see Appendix A for other assumptions and the equations.[10] The HCM has separate procedures for freeways, urban streets, and "highways" (which have design standards

[10] Although there is a newer edition of the HCM (the 2010 version), we use the 2000 version so that the results in this paper are consistent with those presented in Ng and Small (2012).

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between those of freeways and urban streets).[11] We are therefore able to further expand our data set by assuming that FDOT's "arterial" can be either an urban street with traffic signals or a highway (except we assume only an urban street can have a center lane). We assume that highways have grade-separated intersections at all major crossings and there are no signals but like urban streets, there are some at-grade access points (e.g., driveways). It is further assumed that urban streets have one signal per mile while highways and freeways have an interchange with an urban street every two miles. We use the cost estimates for traffic signals and interchanges included in the FDOT dataset and add them to the costs shown in Table 1 (see Appendix B for more detail).

Urban streets require several further assumptions. We assume they have limited parking and little pedestrian activity. We assign speed limits of 45 mi/h and 40 mi/h for the roads with 12-foot lanes and 11-foot lanes, respectively (since free-flow speed depends on, though is not equal to, the speed limit). We also must make assumptions about the number of turn lanes and signal phasing for left-turn lanes (see Appendix A).[12] For each assumed turn-lane and signal configuration, we calculate the saturation flow rate, i.e., the highest flow rate that can pass through a signalized intersection while the light is green, and from that we calculate capacity following the HCM.

The assumptions just described lead to 24 road types, each with its unique cost, capacity, and free-flow speed. From these 24 observations, summarized in Table 2, we fit function $K(V_K,S_f)$ describing initial construction cost.

[11] In deference to this distinction, we use "road" as a general term encompassing all three types, so as to avoid the ambiguity of the term "highway" that exists in the HCM (even in its title) between the general or specific meaning of "highway."

[12] Signal phasing means the types of turns permitted on successive parts of a complete cycle for a traffic signal. The two categories of phasing of primary concern to us are permitted versus protected left turns: "permitted" means left turns are allowed whenever the light is green and there is a gap in oncoming traffic, whereas "protected" means left turns are allowed only with a green arrow during which oncoming traffic is stopped with a red signal.

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Table 2. Road types and construction cost per mile

No. of lanes (two-directional)	Road type	Lane width (feet)	Unimpeded speed (mi/h)	Free-flow speed (mi/h)	Two-directional capacity (veh/h)	Road cost per mile	Signal/interchange cost	Total cost per mile
						(thousands of $)		
2 lanes, undivided	Urban street	12	42.1	35.8	1,277.6	4,794	155	4,949
		11	40.2	34.4	1,245.1	4,647	155	4,802
	Two-lane highway	12	52.5	52.5	3,112.4	4,794	6,716	11,510
		11	47.1	47.1	3,112.4	4,647	6,511	11,158
3 lanes, ctr turn lane	Urban street	12	42.1	35.8	1,637.0	4,769	155	4,924
		11	40.2	34.4	1,582.4	4,581	155	4,736
4 lanes, undivided	Urban street	12	43.1	36.5	1,930.2	5,132	195	5,328
		11	41.2	35.1	1,891.9	4,909	195	5,104
	Multilane highway	12	51.8	51.8	7,306.1	5,132	7,190	12,323
		11	49.9	49.9	7,169.7	4,909	6,877	11,786
5 lanes, ctr turn lane	Urban street	12	43.1	36.5	3,273.1	5,814	195	6,009
		11	41.2	35.1	3,164.0	5,537	195	5,732
4 lanes, divided	Urban street	12	43.1	36.5	3,745.7	7,123	195	7,318
		11	41.2	35.1	3,620.9	6,854	195	7,050
	Multilane highway	12	53.4	53.4	7,421.0	7,123	9,979	17,102
		11	51.5	51.5	7,284.6	6,854	9,603	16,457
	Freeway	12	65.5	65.5	8,455.0	8,875	12,433	21,308
		11	63.6	63.6	8,386.8	8,353	11,702	20,055
6 lanes, divided	Urban street	12	43.5	36.8	5,618.6	7,986	236	8,222
		11	41.6	35.4	5,431.3	7,639	236	7,876
	Multilane highway	12	53.4	53.4	11,131.6	7,986	11,189	19,175
		11	51.5	51.5	10,926.9	7,639	10,703	18,342
	Freeway	12	67.0	67.0	12,763.3	9,858	13,811	23,668
		11	65.1	65.1	12,661.0	9,215	12,910	22,125

Note: We use "free-flow speed" to designate the speed at very low traffic levels, as does Schrank et al. (2012b). The HCM defines it the same way for freeways and highways. But for urban streets, the HCM defines free-flow speed to exclude the effects of "control delay", which is the delay caused at intersections by stopping and/or waiting behind other stopped vehicles while they start up and proceed through the intersection; here we call this the "unimpeded speed." Formulas for calculating both unimpeded speed and control delay are provided by Zegeer et al. (2008) and the HCM (see Appendix A), and used here to compute "free-flow speed" as well as, in the next section, speed as a function of traffic volume.

These estimates imply construction costs per lane-mile, for 12-foot lanes, of roughly $4.0–5.3 million for freeways and $1.3–2.5 million for urban streets, with multilane highways in between. As a comparison, Schrank et al. (2012a) estimate that new construction can cost

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between $5-20 million per lane-mile for freeways, and around $1.5 million for "major surface streets," although their numbers likely include land acquisition costs.

3.2 Estimation of capital cost function

We use a translog function to estimate the relationship between construction cost per mile (denoted by K, measured in thousands of dollars), free-flow speed (S_f), and capacity (V_K), with the right-hand-side variables as ratios to their sample means:

$$\ln K = \beta_0 + \beta_1 \ln(S_f/\overline{S_f}) + \beta_2 \ln(V_K/\overline{V_K}) + 0.5\beta_3 \ln(S_f/\overline{S_f})^2 + 0.5\beta_4 \ln(V_K/\overline{V_K})^2 + \beta_5 \ln(S_f/\overline{S_f})\ln(V_K/\overline{V_K}) + \varepsilon \qquad (8)$$

The sample means for free-flow speed and capacity are 45.80 mi/h and 5,589 veh/h, respectively.

The regression results, using ordinary least squares on 24 observations, are shown in Table 3. Although none of the second-order terms are statistically significant (at a five-percent level), we prefer the second specification because it allows for varying elasticities, even though the estimated extent of variation is not large. Using that specification, the implied elasticities of construction cost with respect to free-flow-speed and capacity are

$$\varepsilon_{K,Sf} = \beta_1 + \beta_3 \ln\left(S_0/\overline{S_f}\right) + \beta_5 \ln\left(V_K/\overline{V_K}\right); \quad \varepsilon_{K,VK} = \beta_2 + \beta_4 \ln\left(V_K/\overline{V_K}\right) + \beta_5 \ln\left(S_f/\overline{S_f}\right).$$

As indicated by the first two coefficients of the right column, these elasticities are 1.36 and 0.40, respectively, when calculated at the sample means. Thus increasing capacity—for example, by building more lanes of a given road type—is subject to strong scale economies, a finding consistent with evidence in Meyer et al. (1965) and Kraus (1981).[13] What is new here, and potentially important, is the finding of scale *dis*economies with respect to free-flow speed. Our estimate suggests that increasing free-flow speed is quite expensive, even holding capacity constant.

[13] Kraus finds scale economies are substantially reduced, though not eliminated, by considering the effects produced by the high cost of enlarging intersections as an entire network of roads is expanded. Such costs are not considered here, at least not explicitly.

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Table 3. Construction cost regression results

Variables	$\ln K$	$\ln K$
$\ln S_f - \ln \overline{S_f}$	1.4401***	1.3552***
	(0.136)	(0.153)
$\ln V_K - \ln \overline{V_K}$	0.3314***	0.3997***
	(0.044)	(0.068)
$0.5(\ln S_f - \ln \overline{S_f})^2$		0.7975
		(1.797)
$0.5(\ln V_K - \ln \overline{V_K})^2$		0.3800*
		(0.218)
$(\ln S_f - \ln \overline{S_f})(\ln V_K - \ln \overline{V_K})$		-0.8708
		(0.520)
Constant	9.3192***	9.3261***
	(0.021)	(0.038)
Observations	24	24
R-squared	0.976	0.982

Note: Standard errors in parentheses.
***, ** and * indicate statistical significance at the 1, 5 and 10 percent levels, respectively.

The regression results can be used to predict construction costs for a range of free-flow speeds and capacities. Figure 1 shows these predicted costs as well as a scatter plot of the actual 24 data points. It provides an illustration of how construction costs increase as both free-flow speed and capacity increase. An exception occurs at extremely low capacities combined with high free-flow speeds, situations that are unrealistic and for which we neither have observations nor wish to do simulations.

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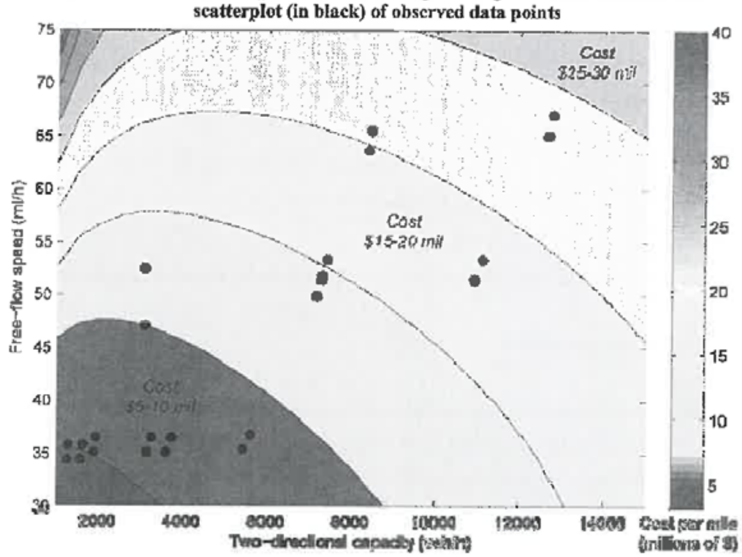
Figure 1. Contour plot of predicted costs using translog coefficient estimates and scatterplot (in black) of observed data points



To estimate the annualized capital cost of building a road, we combine the construction costs (K) from equation (8) with some assumptions on right-of-way acquisition cost (A), the interest rate (r), and the road life in years (Λ), in order to calculate equation (1). Based on Ng and Small (2012), variable A typically ranges from about 3 to 6 percent of total capital cost for urban areas with a population of 0.2 to 1 million people, and is about 18.3 percent for urban areas with one million people or more.[14] Denoting these percentages as x (expressed as a decimal), we can express the right-of-way acquisition cost as a fraction of construction cost: $A = K\cdot[x/(1-x)]$. The annualized capital cost per mile from equation (1) can therefore be rewritten as:

$$\rho(V_K, S_f) = \left(\frac{r}{1-e^{-r\Lambda}} + \frac{rx}{1-x}\right)K(V_K, S_f). \tag{9}$$

[14] These statements from Ng and Small (2012) are in turn based on cited figures from Alam and Ye (2003) and Alam and Kall (2005).

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Given exogenous values of r, Λ and x, the factor in parentheses on the right-hand side of (9) is a constant, which we denote as κ. Taking the natural logarithm of equation (9) and substituting in equation (8) (without the error term) yields:

$$\ln \rho(V_K, S_f) = \ln\kappa + \beta_0 + \beta_1 \ln(S_f/\overline{S_f}) + \beta_2 \ln(V_K/\overline{V_K}) + 0.5\beta_3 \ln(S_f/\overline{S_f})^2 + 0.5\beta_4 \ln(V_K/\overline{V_K})^2 + \beta_5 \ln(S_f/\overline{S_f})\cdot\ln(V_K/\overline{V_K}) \quad (10)$$

Therefore the capital cost elasticities are the same as those from the construction cost function.

4. Speeds and travel times

To determine travel times on the road types described in the previous section, we consider four factors: (1) free-flow-speed; (2) slower speeds, based on the HCM speed-flow curves, when traffic flow increases but is still below capacity; (3) control delay due to traffic signals, applicable only to urban streets; and (4) congestion delay from queuing when demand exceeds capacity. The first three components are based on the HCM procedures described in Appendix A.

The fourth component of travel time, congestion delay, is based on the bottleneck queuing model, which with some minor modifications is the same as that in Ng and Small (2012) as well as in the first example in Section 2. We assume that the bottleneck occurs at the entry to the road, and there are two time periods for one-directional traffic: a "peak" period of duration P (in hours) with constant demand V_p, and an "off-peak" period of duration F with constant demand V_o. A queue (assumed to have zero physical length) builds up if demand exceeds capacity V_K. The model of Ng and Small assumes that the queue gradually discharges when demand falls below capacity, and so if $V_o<V_K<V_p$, off-peak travelers typically experience some queuing delay. However, this would be inconsistent with the assumptions of the theoretical model in Section 2 where it is assumed that travelers in one time period do not affect the travel times of travelers in other time periods (i.e., user cost, c_t, depends only on traffic conditions in time period t and not on those in any other time period). Therefore, when calculating travel times

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in this section we simplify by ignoring the queuing delay experienced by some off-peak travelers; thus off-peak travel times are underestimated when peak volumes exceed capacity.

We assume that the road is 10 miles in length, which is close to the average vehicle trip length of 9.72 miles reported in the National Household Travel Survey (Federal Highway Administration 2009, Table 3). The durations of the time periods are assumed to be $P = 4$ hours and $F = 12$ hours, respectively. (Under our assumptions the value of F does not affect travel time, but it is used later when calculating aggregate travel times for all travelers.)

Average travel times incorporating all four components just described are calculated for each of the 24 road types listed in Table 2 at volume-capacity ratios ranging from 0 to 1.5 (at 0.01 increments). This results in a panel dataset with 3,624 observations of average travel time in minutes, $avgtt_{ij}$, where i indexes road type and j indexes the volume-capacity ratio. We shall refer to these data as the HCM data.

However, these calculations depend explicitly on the road type. Noting that the speed function in equation (3) can be expressed in terms of travel time (T) for a road of length L, $T_f=L/S_f$, we need travel time to depend only on free-flow speed (S_f) and volume-capacity ratio ($v \equiv V/V_K$) in order to apply the theory developed in Section 2. We therefore seek a functional form that can adequately represent the results of our more detailed calculations. The most realistic fit is obtained using a variation of the function proposed by Akçelik (1991) for the purpose of representing both normal flow (volume less than capacity) and queued flow in a single function, as described by Small and Verhoef (2007, eq. 3.11). The original Akçelik travel time function is:

$$T = T_f + 0.25P\cdot\left[(v-1)+\sqrt{(v-1)^2+\frac{8J_a v}{V_K P}}\right] \quad (11)$$

where $T_f=L/S_f$ is free-flow travel time and J_a is a constant taking on different values depending on the type of road, ranging from 0.1 for freeways to 1.6 for high-friction secondary arterials. The term under the square root provides for a modest increase in travel time with v when $v<1$,

GL-9 (Continued)

and for an increase approaching that from deterministic queuing behind a bottleneck when incoming flow is significantly greater than capacity.[15]

To fit with our theoretical model, however, the function cannot depend on road type except through S_f, nor can it depend on capacity except through the ratio $v \equiv V/V_K$. We therefore estimate a variant, motivated by two facts: (i) in Akçelik's derivation, the first term depends on the length of the road L but the second does not since it represents queuing delay at the a single choke point; and (ii) empirically, S_f is positively correlated with (J_a/V_K). The modified Akçelik function is:

$$T - \frac{L}{S_f} = \gamma_1 P\left[(v-1) + \sqrt{(v-1)^2 + (\gamma_2 / P)\exp(\gamma_3 \cdot S_f) \cdot v}\right]. \tag{12}$$

We estimate the equation holding constant P=4 hours and L=10 miles, which are the parameters we use to compute the HCM travel times that are the observations in the estimation. Each observation consists of one of our 24 road types and one of 151 values of v distributed evenly between zero and 1.5.

Our estimates, using nonlinear least squares, are given in Table 4. We note that our estimate of γ_1 is close to the value of 0.25 derived by Akçelik on theoretical grounds, as shown in equation (11).

Table 4. Estimates of modified Akçelik function

Parameter	Estimate	Standard error
γ_1	0.2929	0.0010
γ_2	126.3	38.0
γ_3	-0.1726	0.0085

Note: Based on 3,624 observations. R-squared = 0.9866.

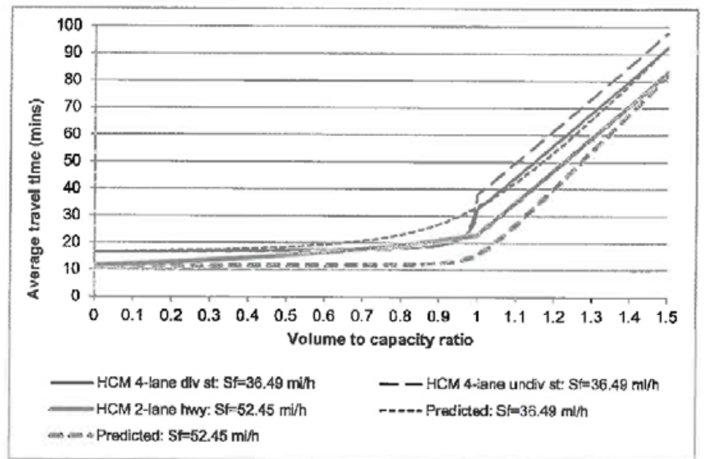
Figures 2 through 4 compare the predicted travel times from equation (12) with those from which it was fitted (what we call "the HCM procedure," which means the HCM supplemented by our queuing model). They do this for a variety of road types with 12-foot lanes.

[15] When the "delay parameter" J_a is zero, this equation simplifies to T=T_f for v≤1 and T=T_f+(1/2)P·[v-1] for v>1.

GL-9 (Continued)

For convenience, travel times are given in minutes. Figures 2 and 3 graph these travel times as a function of volume-capacity ratio v, whereas Figure 4 graphs them as a function of free-flow speed S_f.

Figure 2. Travel times for selected streets and highways



GL-9 (Continued)

Figure 3. Travel times for a four-lane divided highway and freeway

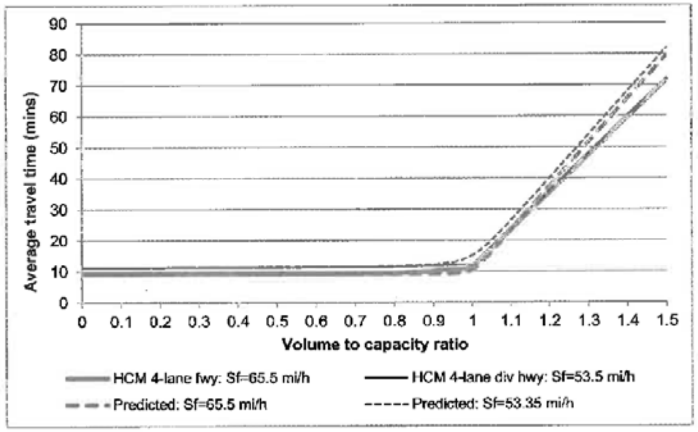
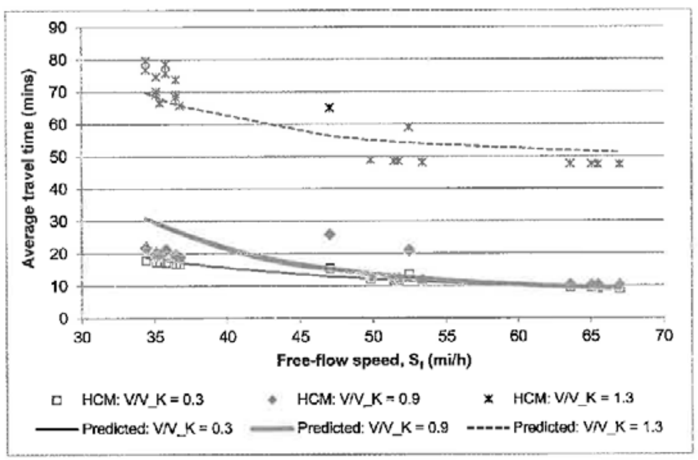


Figure 4. Travel times as a function of free-flow speed, for selected values of volume-capacity ratio



GL-9 (Continued)

In general, the modified Akçelik function reproduces the shapes of the relationships quite well, while eliminating the kinks at v=1 that are an unrealistic artifact of the use of different procedures for v<1 and v>1. Especially helpful is that the modified function eliminates the unrealistic non-convexity at v=1 that occurs in our HCM procedure for urban streets, seen in Figure 2. The modified Akçelik function also captures the feature, arising directly from the HCM, that the travel time function is very flat almost up to v = 1 for higher road types. However, it underestimates travel times for two-lane highways because it interprets their relatively high free-flow speed as indicating a high road type, whereas actually traffic slows noticeably on two-lane highways even for moderate traffic levels. When queuing occurs (e.g., at v =1.3 as seen in Figure 4), predicted travel times are slightly underestimated for urban streets and two-lane highways, and overestimated for multilane highways and freeways.

Figures 2 through 4 show that our modified Akçelik function is convex in both traffic level (v) and free-flow speed (S_f). This guarantees that second-order conditions for cost minimization are met, so we do not need to explicitly derive and calculate values for those conditions.

The derivatives of the modified Akçelik function lead to the following values needed to calculate equations (5c):

$$(L/\alpha)c\varepsilon_{S,Sf} \equiv T\varepsilon_{S,Sf} = \frac{L}{S_f} - \frac{\gamma_1\gamma_2\gamma_3 v S_f \exp(\gamma_3 S_f)}{2z} \qquad (13)$$

$$(L/\alpha)mecc \equiv v\frac{\partial T}{\partial v} = \gamma_1 P v\left(1+\frac{v-1}{z}+\frac{\gamma_2 \exp(\gamma_3 S_f)}{2Pz}\right) \qquad (14)$$

where

$$z = \left[(v-1)^2 + \frac{\gamma_2 v}{P}\exp(\gamma_3 S_f)\right]^{1/2}.$$

GL-9 (Continued)

The asymptotic slope of (14) is proportional to P, just as for a simple bottleneck.[16]

5. Numerical results for investment balance

We now apply the model to some examples of roads to see under what conditions these roads embody the optimal balance between S_f and V_K indicated by equations (5c). In Section 5.1 we consider a wide selection of roads and traffic levels, in order to explore the range of conditions when each type of road is appropriate. In Section 5.2 we look at empirical data to see whether representative roads in various cities would better serve their areas with a different type of design. In Section 5.3, we go further and examine the absolute criteria for investing in capacity or free-flow speed, i.e. equations (5a-b), for the same sample of cities and for a hypothetical example illustrating the possibility of trading off free-flow speed against capacity.

5.1 Sampling the universe of urban road conditions

We first consider the investment balance condition for the specific road types we have been analyzing, shown in Table 2. We do so for peak volume-capacity ratios ranging from 0.1 to 1.25, holding constant the peak and off-peak durations (P=4 hours and F=12 hours, respectively), the ratio of peak to off-peak volume (V_p/V_o=1.25), and other assumptions taken from Ng and Small (2012).[17] We believe these assumptions are relatively favorable to investment in free-flow speed; in particular, many congested cities probably have considerably higher values of V_p/V_o.[18]

[16] As $v \to \infty$, the second term in parentheses in (14) approaches 1 while the third term disappears, so that $\partial T/\partial V \to 2\gamma_1 P/V_K$. If γ_1 were equal to 0.25 as in the original Akçelik formula, this would be exactly the asymptotic slope of the average wait through a bottleneck of capacity V_K over period P when that capacity is exceeded, as in equation (6). This is why our predicted travel-time curves rise nearly linearly with traffic at high traffic levels in Figures 2 and 3; their slopes are slightly higher than for the "HCM procedure" because our estimate of γ_1 slightly exceeds 0.25.

[17] These are: Peak period (in a given direction) occurs 310 days per year; off-peak period occurs for 12 hours/day on those same 310 days, and also occurs for 16 hours/day on the other 55 days.

[18] According to Hu and Reuscher (2004), 59 percent of all national person trips occur during the twelve off-peak hours defined by 9 a.m. – 1 p.m. and 4–10 p.m. If it is evenly divided in direction, this amounts to about 5 percent of trips per hour on a one-directional roadway. Another 37 percent, or 6 percent per hour, occur within the six peak hours 6–9 a.m. and 1–4 p.m. This would imply a national average peaking ratio of V_p/V_o =6/5=1.2 if the peak trips

GL-9 (Continued)

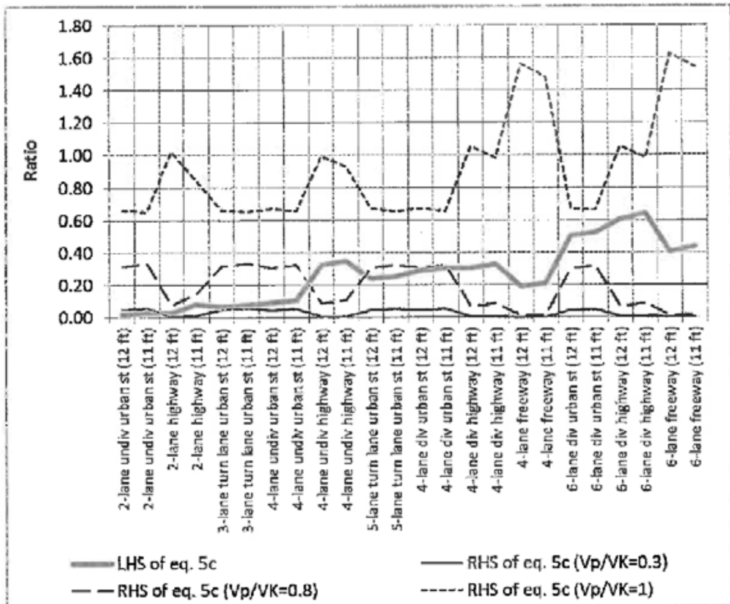
Some results are shown in Figure 5 (Appendix C has further details). The thick line shows the left-hand side of equation (5c) (the ratio of construction cost elasticities); whereas the thin and the dashed lines show the right-hand side (the ratio of marginal user costs) for three values of peak volume-capacity ratio (V_p/V_K). Incremental investment in S_f is more favorable than investment in V_K when the ratio of construction cost elasticities exceeds the ratio of marginal user costs, i.e., when the thick line lies above the thin or dashed line. We can see that when $V_p/V_K = 0.3$, investing in S_f is more beneficial for all types of roads except two-lane urban streets. But under highly congested conditions, as when $V_p/V_K = 1$, investment in S_f is never favored: rather, it is always better at the design stage to sacrifice some free-flow speed in order to increase capacity.

The intermediate case where $V_p/V_K = 0.8$ is illuminating. With this level of peak traffic, all the highways and expressways of four lanes or more offer inefficiently high free-flow speeds relative to their capacity; whereas two-lane highways and two- to five-lane urban streets would benefit relatively more from expanding free-flow speed. A corollary is that if peak traffic congestion is at this level and if capacity is being optimized as called for by (4a), then (4b) indicates that the most highways and expressways exhibit over-investment in free-flow speed under the design standards embedded in the Florida cost data.

are distributed evenly across directions, or 9/5=1.8 if half of the peak trips are concentrated in one direction (inbound in the morning, outbound in the afternoon).

GL-9 (Continued)

Figure 5: The investment balance condition (5c) for 24 road types



Note: Investment in S_f is favored relative to that in V_K when the LHS (ratio of construction cost elasticities: thick line) exceeds the RHS (ratio of marginal user costs: thin and dashed lines).

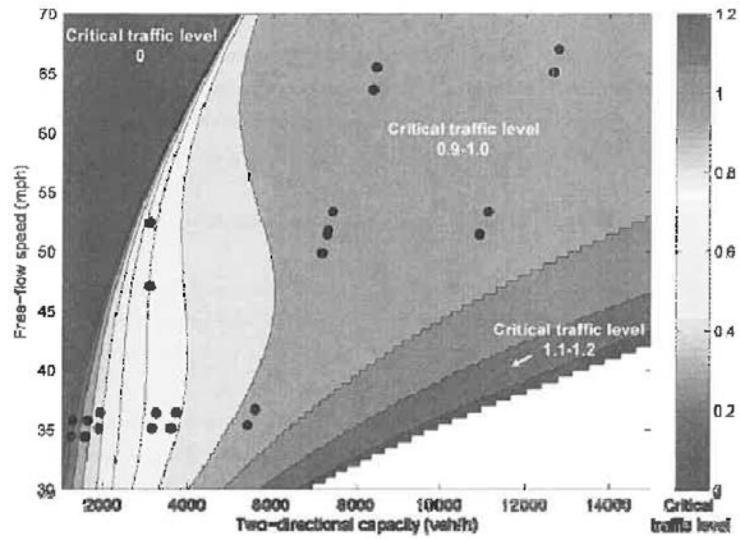
While these results are computed for a particular ratio of peak to off-peak traffic volume (V_p/V_o=1.25), they are quite insensitive to that ratio.[19] As we shall see, however, the analysis of a large discrete change can be more sensitive to this assumed ratio.

[19] This is because, as V_p/V_o increases, both the marginal external congestion cost and the average user cost of peak travelers rise relative to those of off-peak travelers; but since one is in the numerator and the other in the denominator of the ratio of marginal user costs, that ratio, which is the right-hand side of (5c), remains relatively constant. The left-hand side of the equation does not depend on traffic volumes at all; thus, the relationship between the two sides of the equation is relatively unaffected.

GL-9 (Continued)

Figure 6 broadens the computations to a wide range of free-flow speeds and capacities. For each combination of these two investment variables, it displays the "critical traffic level," defined as the maximum value of V_p/V_K for which the ratio of construction cost elasticities exceeds the ratio of marginal user costs (a situation favoring investment in free-flow speed relative to that in capacity). In other words, for any given road type, investment balance is realized when peak traffic congestion is described by the critical traffic level; if congestion is less the road is too slow at low flows, whereas if congestion is greater the road is over-invested in free-flow speed.

Figure 6. Critical traffic levels for various free-flow speeds and capacities, and scatter plot (in black) of FDOT road types



Note: The critical traffic level is the maximum V_p/V_K for which incremental investment in S_f is more favorable than investment in V_K, according to equation (5c). It is calculated for 0.5 mi/h increments of free-flow speed and 20 veh/h increments of two-directional capacity.

GL-9 (Continued)

In the upper left portion of the figure, with high free-flow speed but low capacity, the critical traffic level is zero: investment in capacity instead of free-flow speed is strongly preferred. As free-flow speeds and capacities rise, in general the critical traffic level increases; for many types of roads, it is between 0.9 and 1.0 (just before queuing begins), which is intuitive because queuing causes the marginal external congestion cost to rise significantly, making the case for capacity investment much more compelling. In the unshaded lower right portion of the figure, the critical traffic level is not calculated but is probably greater than 1.25;[20] these are high-capacity roads with low free-flow speed that would strongly benefit from incremental investment in free-flow speed.

For the road types in our sample, shown as black dots in the figure, the critical traffic levels range from 0.1 to 0.5 for urban streets of less than five lanes, and from 0.6 to almost 1.0 for all other road types. Corresponding average peak speeds for these critical traffic levels, shown in Appendix C, range from 28 to 36 mi/h for urban streets and two-lane highways, and from 47 to 56 mi/h for multilane highways and freeways. It is apparent that whenever there is substantial peak congestion, a reconfiguration of these roads to extract more capacity at the expense of free-flow speed would be beneficial if it could be done at the design stage.

5.2 Investment balance for typical urban roads in the United States

We now examine the investment balance condition for some road conditions observed in US urban areas in 2011. We use the average free-flow speed and average peak speed for "freeways" and "arterials", as compiled by the Schrank et al. (2012b), for "very large" and "large" urban areas.[21]

To compute the investment balance condition, we also need to know road capacity and peak volume-capacity ratio. We combine data on road mileage from the Federal Highway Administration's *Highway Statistics* (2013) with lane-miles data from Schrank et al. (2012b) to obtain the average number of lanes for freeways and arterials in each urban area and use this to

[20] The critical values are not calculated explicitly here because this region violates our model's assumption that $V_o/V_K < 1$ (i.e., off-peak volumes do not encounter queuing).

[21] These areas are defined as having population more than 3 million and 1–3 million, respectively. The data are from Schrank et al. (2012b), Appendix A, Exhibit A-8.

GL-9 (Continued)

estimate capacity, assuming that arterials are equivalent to urban streets with signals (see Appendix C for details). Knowing both free-flow speed and peak speed, we can solve (12) iteratively to determine the peak volume-capacity ratio v_p; we then assume v_p/v_o=1.25, as before, to get the off-peak ratio. Thus, for each urban area we have a representative "average" road (either a freeway or arterial) with unique free-flow speed, capacity, and peak/off-peak volume-capacity ratio; we use this information to calculate the two sides of the investment balance condition (equation [5c]). Note that because our calculations are highly non-linear, the investment balance for a representative road does not necessarily apply to the entire urban area.

We present the results of a sample of seven urban areas, chosen to cover most of the range of observed speeds on each road type, in Table 5.

GL-9 (Continued)

Table 5. Investment balance for average road conditions in seven urban areas, 2011

	Very large areas				Large areas		
	Los Angeles	Dallas-Fort Worth	Miami	Boston	Denver	St. Louis	Jackson-ville
Freeways:							
Average no. of lanes	8.7	5.8	6.7	6.4	5.8	6.5	5.8
Free-flow speed, S_f (mi/h)	64.6	64.1	64.0	63.4	62.3	56.0	63.4
Peak speed, S_p (mi/h)	48.6	54	56.7	54.2	50.9	44.4	58.9
Peak volume-capacity ratio, V_p/V_K	1.016	1.003	0.994	0.999	1.004	0.993	0.976
Ratio of construction cost elasticities	0.95	0.43	0.58	0.54	0.48	0.77	0.45
Ratio of marginal user costs	2.55	1.67	1.12	1.42	1.66	0.99	0.46
Imbalance (+ favors investment in S_f)	-1.60	-1.23	-0.54	-0.88	-1.18	-0.21	-0.01
Arterials:							
Average no. of lanes	3.6	3.7	4.6	2.3	3.5	3.2	3.7
Free-flow speed, S_f (mi/h)	43.7	39.1	39.2	36.0	38.0	34.9	43.3
Peak speed, S_p (mi/h)	37.4	33.1	31.7	29.5	32.1	29.8	37.4
Peak volume-capacity ratio, V_p/V_K	0.811	0.695	0.758	0.639	0.662	0.534	0.788
Ratio of construction cost elasticities	0.13	0.20	0.30	0.06	0.20	0.21	0.15
Ratio of marginal user costs	0.20	0.17	0.22	0.17	0.16	0.13	0.19
Imbalance (+ favors investment in S_f)	-0.08	0.04	0.08	-0.12	0.04	0.08	-0.04

Note: The imbalance is calculated as the ratio of construction cost elasticities minus the ratio of marginal user costs.
Sources: Schrank et al. (2012b), FHWA (2013), and authors' calculations; see text and Appendix C for more details.

From Table 5, we can see that the overall picture is that freeways demonstrate an over-investment in free-flow speed relative to capacity, whereas for arterials these two dimensions of investment are quite well-balanced. For example, despite its already high capacity, a representative Los Angeles freeway would benefit more from further capacity expansion than from further investment in free-flow speed, due to heavy congestion (second-lowest peak freeway speed among all urban areas). Peak freeway speed is lowest in St. Louis; but so is its

GL-9 (Continued)

free-flow speed, and as a result its investments are much closer to balance although still favoring capacity expansion. To put it differently, the case for giving up some free-flow speed in exchange for more capacity (for example by restriping for narrower lanes) is less strong in St. Louis than in Los Angeles.[22]

For arterials, the imbalance is generally quite close to zero. The biggest imbalance is in Boston, for which an unusually small average lane width and high congestion imply a relative preference for capacity. In Miami and St. Louis, there is a slightly greater incremental benefit from improving arterial free-flow speeds than for expanding arterial capacity. Increasing free-flow speed for arterials—which here are assumed to be urban streets with signals—need not necessarily imply upgrading to a higher road type, but could involve targeted upgrades to reduce delays from traffic signals. Such upgrades are analyzed by Samuel (2006, ch. 4), who describes a number of innovative intersection designs that improve both free-flow speed and capacity with modest cost and land requirements. Since these improvements also increase capacity, it is unclear without more detailed analysis what their availability implies for investment balance as defined here.

5.3 Absolute investment criteria

In addition to examining the relative investment criterion, we can analyze the absolute investment criterion for either capacity or free-flow speed, each holding the other constant. The criteria are contained in equations (4a) and (4b), respectively, or equivalently (5a) and (5b). We summarize by calculating the benefit-cost ratio as the travel time savings from an incremental increase in free-flow speed divided by the corresponding incremental capital cost. From equation (5a), investment in V_K is warranted if the benefit-cost ratio exceeds one:

[22] We perform a sensitivity analysis by assuming P=2 and F=14 instead and reestimating the travel time function. Since there are now fewer vehicles affected by congestion and for a given value of v_p, there is also less congestion, many road types now have a higher critical traffic level (defined in Section 5.1), i.e., there are now more instances where incremental investment in S_f rather than V_K is beneficial. As a result, in many urban areas, the freeway imbalance becomes positive though very close to zero, in contrast to the case of P=4 where nearly all of the imbalances were negative; whereas the arterial imbalance is still fairly similar (close to zero). We consider the assumption of P=4 for one-way travel to be more realistic and it is in line with Schrank et al.'s (2012b) definition of peak hours as 6-10 a.m. and 3-7 p.m., but it is useful to keep in mind that the "balance" for a real road depends quite sensitively on the peaking characteristics.

GL-9 (Continued)

$$\frac{B}{C} \equiv \frac{\sum_t q_t V_t \cdot (mecc)}{\rho c_{\rho, VK}} > 1. \tag{15a}$$

Similarly, equation (5b) yields the investment criterion for free-flow speed:

$$\frac{B}{C} \equiv \frac{\alpha \sum_t q_t V_t T_t \left(\varepsilon_{S,Sf}\right)_t}{\rho L \varepsilon_{\rho,Sf}} > 1. \tag{15b}$$

The components of these equations can be computed using equations (10), (13), and (14) along with assumptions about amortization, land acquisition, value of time, duration of travel periods, capacities, volume-capacity ratios, and trip length.[23]

One can alternately view this calculation as the maximum cost multiplier that could justify the investment under consideration, where by "cost multiplier" we mean the incremental cost of expanding either S_f or V_K for a given hypothetical project, divided by the corresponding incremental cost as observed in our Florida cost data. Even so, this calculation should not be taken too literally, because it does not account for induced traffic: the tendency of greater capacity to attract new users. As a result, it will exaggerate the benefit-cost ratio that could be achieved in reality, as demonstrated by SACTRA (1994). In addition, we reiterate that we have less confidence in the absolute than in the relative calculations.

Table 6 shows the results for the sample of cities already discussed in Section 5.2. Using these figures, the case for investment is strong in both dimensions, in all areas. The variations across cities are not surprising. The case for investment in freeway capacity is extremely strong in Los Angeles, with its low average peak freeway speed, and much less so in relatively uncongested Jacksonville. For arterials, the case for capacity investment is strongest in Boston and weakest in St. Louis. The case for investment in greater free-flow speed is strongest for St.

[23] In addition to the assumptions mentioned in previous sections, we need values for the interest rate (r), lifetime of the road (Λ) and land acquisition costs as a percentage of total capital cost (x) to calculate ρ using equation (10). Based on Ng and Small (2012), we set r=0.07, Λ=25 years and x=0.183 (since the urban areas in our sample have populations of 1 million or more). We use the same value of time per vehicle as Schrank et al. (2012b), namely $16.79/hr, who base their figure on McFarland and Chui's (1987) estimate, updated to 2011 dollars, and on assumed average vehicle occupancy of 1.25.

GL-9 (Continued)

Louis freeways and Miami arterials, while weakest for Jacksonville freeways and Boston arterials.

Table 6. Absolute benefit-cost ratios from incremental investments, assuming Florida capital costs and no induced traffic

	Very large areas				Large areas		
	Los Angeles	Dallas-Fort Worth	Miami	Boston	Denver	St. Louis	Jackson-ville
Freeways:							
Free-flow speed, S_f (mi/h)	64.6	64.1	64.0	63.4	62.3	56.0	63.4
Capacity, V_K (veh/h)	18,519	12,307	14,268	13,616	12,382	13,736	12,322
Capital cost, ρ (1000 $ per year per mi)	2,789	2,278	2,426	2,356	2,224	2,147	2,256
B/C: incr. invest. in V_K	49.2	37.0	23.4	30.8	37.8	25.0	9.4
B/C: incr. invest. in S_f	18.3	9.6	12.0	11.7	10.9	19.6	9.2
Arterials:							
Free-flow speed, S_f (mi/h)	43.7	39.1	39.2	36.0	38.0	34.9	43.3
Capacity, V_K (veh/h)	3,216	3,337	4,284	1,589	3,123	2,751	3,393
Capital cost, ρ (1000 $ per year per mi)	879	732	810	522	682	563	877
B/C: incr. invest. in V_K	8.6	5.9	8.4	11.4	5.6	3.9	7.1
B/C: incr. invest. in S_f	5.4	7.2	11.4	3.8	7.0	6.2	5.7

Note: B/C is the benefit cost ratio from incremental investment in capacity (V_K) and free-flow speed (S_f) calculated using equations (15a) and (15b), respectively.

Finally, we present an example of a situation where one can trade off an increase in capacity for a decrease in free-flow speed by choosing among two road types. Here we depart from our incremental analysis using continuous functions, and instead perform straightforward cost-benefit calculations. Each calculation considers replacing plans for a standard six-lane freeway by instead building two undivided four-lane highways with below-standard lane widths. The two highways combined are slightly more expensive to build and provide 12 percent more capacity, but at a cost of 26 percent lower free-flow speed. For this example, we assume the freeway would encounter peak travel time of just under 30 minutes for a 10-mile trip, which is

GL-9 (Continued)

associated with a peak volume-capacity ratio of 1.15. Having the same number of vehicles distributed evenly across the two highways would give each of these roads a peak volume-capacity ratio of 1.02.

Results are shown in Table 7. Using the same peaking assumption as before, that the ratio of peak to off-peak volume is 1.25, building the two highways instead of the freeway saves more than 10 minutes per peak trip, but adds nearly 4 minutes per off-peak trip. Thus, the six-lane freeway is preferred since both its capital cost and total user time cost are lower. However, if we assume instead that V_p/V_o=1.5, i.e., we have the same peak volume as before but there are now fewer vehicles during off-peak hours, then off-peak travel time on the highways increases by just 3.5 minutes relative to that on the freeway and total user time actually decreases. As it happens, the value of this time savings is worth more than the extra capital cost, yielding a benefit-cost ratio of 2.64.

Table 7. Example of tradeoff between free-flow speed and capacity

	V_p/V_o = 1.25		V_p/V_o = 1.50	
	6-lane freeway (12 ft)	Two 4-lane undiv hwys (11 ft)	6-lane freeway (12 ft)	Two 4-lane undiv hwys (11 ft)
Free-flow speed, S_f(mi/h)	67.0	49.9	67.0	49.9
Capacity, V_K (veh/h)	12,763	14,339	12,763	14,339
V_p/V_K	1.15	1.02	1.15	1.02
V_o/V_K	0.92	0.82	0.76	0.68
Average peak travel time, T_p (min)	29.6	19.0	29.6	19.0
Average off-peak travel time, T_o (min)	9.1	12.9	9.0	12.5
Capital cost, ρ (million $ per mi)	2.41	2.78	2.41	2.78
Total user time cost (million $ per mi)	28.66	29.10	26.29	25.30
Total cost (million $ per mi)	31.07	31.88	28.69	28.08
Incremental benefits, B (million $ per mi)		-0.43		0.99
Incremental capital cost, C (million $ per mi)		0.37		0.37
B/C		-1.15		2.64

Note: All benefits and costs are per year, and the incremental benefits/capital cost are calculated based on building two four-lane undivided highways instead of one six-lane freeway.

GL-9 (Continued)

Intuitively, because the two highways offer more total capacity at the expense of free-flow speed, they are beneficial to peak travelers at the expense of off-peak travelers. In general, we would expect that this type of tradeoff would be more favorable to the higher-capacity option when V_p/V_o is high.

This example is motivated in part by Samuel (2006), who argues that most US cities have major roads that are too wide and too sparsely spaced. Samuel argues the point from a different perspective, involving the engineering inefficiencies of intersections between very wide roads. Our approach, which recognizes explicitly the tradeoff between the needs of peak and off-peak travelers, thus complements his. While our earlier analysis of investment balance does not strictly apply to this discrete example, it does give some clues. In this example, the "investment balance" for the freeway (not shown in the table) is -4.5 at the higher ratio of peak- to off-peak traffic; that is, at the margin, the freeway offers too high a free-flow speed relative to capacity. The highway, by contrast, is much closer to balance, with value -1.0. Thus, it is perhaps not surprising that the freeway investment turns out unfavorable in this case.[24]

6. Conclusion

When free-flow speed is distinguished as an additional dimension of road investment, it becomes possible to analyze some important questions about road design within an optimization framework familiar to economists. Specifically, we can analyze criteria for investment not only in road capacity but in free-flow speed, which effectively means choosing among road types and/or specific design criteria such as lane widths. There is sufficient independence between these two dimensions that one can not only analyze each individually, but consider the optimal balance between them.

Empirically, we find that despite the discreteness of road types, it is feasible to approximate the range of possibilities by analytical functions describing capital cost and user time costs as functions of capacity and free-flow speed. Doing so will not answer a specific design question for a specific road, but it is useful for broad-brush analyses of road policy, such as occurs in discussions about what type of road network a city needs. Our empirical analysis

[24] However, the investment balance, an incremental criterion, is not nearly as sensitive to V_p/V_o as is the benefit-cost criterion for this discrete investment example: at V_p/V_o=1.25, the balance is -3.7 for freeways and -0.8 for arterials.

GL-9 (Continued)

provides suggestive evidence that in many large congested cities, standard expressway designs are unbalanced in the sense of providing more free-flow speed than is desirable relative to capacity; whereas the same is not true for urban streets and arterial highways. This observation in turn suggests giving greater attention to the possibilities of more low-footprint roads which offer considerable capacity even though speeds are only moderate even at low traffic levels.

There are numerous factors not considered here that would be beneficial to add to this type of analysis. We mention a few here.

First, as emphasized by Ng and Small (2012), these design features have implications for safety which are potentially important but not well understood empirically. Furthermore, these safety implications could change dramatically as technologies, social customs, and legal environments evolve.

Second, some design features that reduce free-flow speed, such as reduced lane or shoulder widths, would be easier to undertake if large trucks are excluded from the road. Therefore, if one wants to use our analysis to reexamine policy toward road design, it would be a good time to also reexamine policy toward separating trucks and cars onto different roads.

Third, a broad policy analysis is likely to affect networks of roads, not just individual roads, which raises the question of how intersections affect costs. Kraus (1981) finds that accounting for the cost of intersections substantially decreases the measured scale economies with respect to capacity, because intersection costs tend to rise more than proportionally to the capacities of the intersecting roads. Whether any similar conclusion would apply for the elasticity of road costs with respect to free-flow speed would be extremely interesting and potentially important to discover.

Fourth, applications to particular road investments need to distinguish a finer time pattern of demand, to reduce inaccuracies caused by applying nonlinear relationships to averages. Doing so could also necessitate accounting for demand shifts across times of day. Alternatively, one might consider continuous-time models, such as the "bottleneck model" of Vickrey (1969) and Arnott et al. (1991), which deal with both issues simultaneously.

Fifth, our analysis does not include induced demand, i.e., the tendency of a road improvement to attract new traffic. This might well affect investment balance as well as the absolute investment criteria. To analyze this, one would need to have a more microscopic picture

GL-9 (Continued)

of induced demand than is common, relating it specifically to increases in average speed by time period.

Finally, the potential for road pricing to reduce congestion would substantially change the optimal balance analyzed here, probably in favor of less capacity and more free-flow speed. Thus, our model suggests another potentially important long-run implication of road pricing: changing the nature as well as the capacity of a desirable urban road network.

With these and other improvements, we believe our approach to modeling road investment offers the potential for expanding insights and increasingly sophisticated practical analysis, all of which could enhance the efficiency with which roads are provided.

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GL-9 (Continued)

GL-9 (Continued)

Notation

t	Index for time periods, $t = 1,2,\ldots,n$
q_t	Duration of time period t
V_t	Traffic volume at time t
V_K	Capacity
v_t	Volume-capacity ratio (V_t/V_K)
S_f	Free-flow speed (including control delay at zero traffic volume for urban streets)
S_t	Average speed
T_t	Average user time (entire trip)
ρ	Annualized road capital cost (per mile)
r	Interest rate
Λ	Lifetime of road in years
L	Trip length
$K(\cdot)$	Road construction cost (per mile)
$A(\cdot)$	Right-of-way acquisition cost (per mile)
c_t	Average user cost per vehicle-mile at time t
U_t	Total user cost per road-mile per hour at time t
C	Total agency plus user cost (short run) per road-mile
$\tilde{C}$	Total agency plus user cost (long run) per road-mile
α	Value of time

Attachment 6

City of Seal Beach
Studebaker Road/College Park Drive Alternative
Street and Ramp Configuration
July 2013